REPORT No. 77

THE PARKER VARIABLE CAMBER WING

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BY H. F. PARKER.

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THE PARKER VARIABLE CAMBER WING.[1]

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[Introduction—Rib structure—Rib tests; Conditions of test; Results of tests—Aerodynamical tests—Discussion of Wind tunnel results; Monoplanes biplanes; triplanes—Summary.]

INTRODUCTION.

The most important single problem in aeronautics awaiting solution is that of increasing the speed range of airplanes. In recent years maximum speeds have been increased very greatly, and will no doubt be still further increased, but each addition has been accompanied by an increase in the landing speed. The landing speed has always been about half the maximum and could not be reduced below that amount without entailing the expenditure of additional power. This is due primarily to the properties of the type of wing which has been used.

In flying, the method utilized to change the speed is to alter the angle of attack of the planes. This must also be accompanied by an alteration in the power output of the engine if the machine is to be kept flying level. Manipulation of the engine throttle without alteration of the angle of the planes will not cause a change in speed; the machine will ascend or decend at its former speed. The speed is therefore dependent on the angle of attack. If this could be efficiently varied from a very small to a very large angle, a wide range of speeds could be obtained. Two things prevent this: First, the lift does not increase directly with the angle of incidence for all angles. It does do so up to about 15° but for greater angles, instead of increasing, the lift actually falls off. This falling off occurs in all types of wings though in some cases it is only slight and in others very considerable. It is well shown in the lift curves in figure 14, and is also apparent in all the other lift curves shown in this report—in figures 8, 17, and 20. Consequently no increase in speed range can be obtained by increasing the angle of incidence beyond 15°. Second, the efficiency of the plane is not maintained at low angles. As the incidence is reduced from the maximum of 15°, both the lift and the drag decrease, the drag at first falling off more rapidly than the lift. At about 3° a point is reached where the ratio of lift to drag is a maximum. This is the most efficient flying angle for the plane. As the incidence is further decreased, the lift continues to fall off rapidly. The drag, however, decreases more slowly, being a minimum at zero incidence. For negative angles it again increases.

This means that the ratio of lift to drag falls off very rapidly, and the wings of a machine flying at a smaller angle of incidence than 3° offer more resistance than they do at that angle. The line from which these angles are measured is the chord of the aerofoil, i. e., the common tangent to the lower surface. It will be noticed that this is not necessarily the position in which the wing gives no lift. Most wings give a considerable lift when their chord line is parallel to the direction of the air flow, and this lift only becomes zero when the nose of the wing is about 3° below the trailing edge. In fact, fast machines frequently fly with their planes set at negative angles.

If a maximum speed of double the minimum is to be obtained, the machine must fly under the inefficient conditions existing at these small positive or even small negative angles of incidence. If it is to be more than double, as it must be in order to obtain a reasonable landing

[1] At the time this wing was designed it was Mr. Parker's belief that the wing would be automatic in operation. Subsequent examination indicates that this is not true, at least for the rib as now designed. Means for flexing the wing mechanically are not discussed.—*Ed.*

speed in machines flying at over 100 miles an hour, the small lift necessary at high speeds is accompanied by a prohibitive drag.

The problem of increasing the speed range may be approached in a number of ways, but confining ourselves to devices applicable to the present type of airplane, which eliminates the helicopter and similar machines, there are three ways by which a solution might be achieved. These are:

Variable angle of incidence.
Variable surface.
Variable camber.

Each of these presents great mechanical difficulties, but the first is the easiest of attack and has consequently approached nearer a solution than either of the other two. It offers two advantages: First, the axis of the fuselage can be kept parallel to the path of flight at all speeds, thus securing a minimum drag over the entire speed range. In the present machine, having the wings fixed in relation to the fuselage, the fuselage is at a considerable angle to the flight path over a portion of the speed range. Under these conditions the variable incidence machine is more efficient than the present type. Over that portion of the speed range where the fuselage of the standard machine lies along the flight path, or only a few degrees from it, the variable incidence machine offers little or no advantage. Second, the wings of the variable incidence machine can be tilted to a much greater angle than is possible in the present machine. This permits the machine to be brought to rest more rapidly. It does not, however, reduce its minimum flying speed. Thus the advantages of variable incidence, though well worth attainment, do not provide a sufficiently complete solution of the problem.

The next for consideration is variable surface. Theoretically, this gives a perfect solution. If the wings of the airplane could be increased in area during flight, the speed could be reduced so as to land as slowly as desired. Conversely, given sufficient surface to insure a low enough landing speed, if the surface could be reduced in flight the planes could always be made to operate at the angle of incidence giving the best lift/drag ratio, thus securing the least possible drag at maximum speeds. Unfortunately, mechanical difficulties prevent the realization of this method. These difficulties are so serious that there does not seem any prospect of their being overcome in the near future.

Finally, there is variable camber. This offers advantages very much greater than variable incidence, but is more difficult of solution mechanically. On the other hand, as compared with variable surface, it is mechanically possible, but its aerodynamic advantages are not quite so great. Yet they are, however, great enough to provide a satisfactory solution of the problem and the only one, apparently, which is practicable.

So much for the accepted methods of increasing speed range. The method under discussion in this paper can not be properly classified under any of these headings. In conception, however, it is derived from variable surface, though the mechanical device utilized is distinctly variable camber.

Let us return to the conception of variable surface. A machine so equipped would have a comparatively small amount of fixed surface, together with a larger amount of removable surface. While landing, both fixed and removable surface would be in operation, but at high speeds the fixed surface alone would support the machine. Assuming that a mechanical device to operate such a system is possible, it is obvious that the mechanism would entail a considerable increase in weight, and probably also in head resistance. This may be expressed in terms of the resistance of the wings that have been removed. For example, 100 units of drag may have been eliminated by removing a portion of the wings, but the equivalent of 20 added by the extra weight and increased resistance. This, then, would leave us a net saving of 80 units.

Suppose, now, that instead of removing the wings we leave them in place, but when they are not required for lifting we change them to a shape offering only a fraction of their former drag. If this fraction is approximately the same as that required for variable surface we will have all the advantages of variable surface, and the problem will become one of changing the wing from an efficient lifting shape to a shape offering the least possible resistance; for example, pure stream line. Experimental results show that such a saving can be effected; the drag can be reduced from 100 units to 25, giving us a net saving of 75 units. In a biplane the upper plane will be of fixed construction and the lower one variable, or vice versa; while in a triplane a suitable arrangement is obtained by using a fixed wing for the center plane and placing variable wings above and below it. At high speeds the variable planes are to carry no load and are to be stream line in shape. At low speeds they are to bear their share of the weight of the machine and are to be deeply cambered. For a stream-line wing to give no lift it must lie parallel to the direction of the air flow, and then the forces on its upper and lower surfaces are equal. It is necessary, therefore, to set the stream-line planes at zero angle of attack when the fixed planes are at their angle of maximum lift/drag, usually about 3°.

For slower speeds the angle of attack of the fixed plane must be increased, let us say, from 3° to 9°, a change in angle of 6°. The stream-line plane is carried through the same angle and now has unbalanced forces acting on it, tending to deform it upward. These forces are the greatest near the leading edge, and decrease rapidly as the trailing edge is approached. If we place one wing spar at the leading edge and another about two-thirds of the chord back from it, we divide the wing into two parts, with the force on the front part very much greater than that on the rear part. If, now, we make the part between the spars of flexible construction and the part behind the rear spar rigid, and allow the ribs to slide over the rear spar, we provide for a change of shape under load. The portion between the spars is carried upward, while the rear portion, being rigid and fixed to it, moves downward. The result is a cambered wing.

The rib should be just rigid enough to deform a certain desired amount under the maximum load it should carry normally, and the deformation should be proportional to the load upon the rib up to full load. The load at any time will depend on the ratio of the lift coefficient of the variable plane at its angle of attack to the lift coefficient of the fixed plane at its angle. Thus, at maximum speed when the variable plane is stream line in shape the proportion is zero to the lift coefficient of the fixed plane, and the load is zero. At landing speed the lift coefficients of the two planes are approximately equal—the variable plane is carrying half the load and its load and deflection are a maximum. In an intermediate case, when the planes are at 6° and 9°, respectively, the lift coefficients are, let us say, 1:3. The variable plane is now carrying a quarter of the load, or one-half its maximum load, and its shape will be halfway between the extremes. It is now a lifting aerofoil, but a lightly cambered one. As lightly cambered aerofoils are most efficient at small angles, and heavily cambered ones at large angles, the variable wing possesses the most suitable shape throughout its range.

If the decalage remained unchanged, i. e., if the setting of the variable plane relative to the fixed plane remained the same for all angles of attack, when the fixed plane was at its angle of maximum lift the variable plane would be 3° short of it, and would not be operating under the best conditions. This is not the case, however. In changing the shape of the wing the trailing edge was depressed and the angle of attack in consequence was increased. This change in decalage is dependent on the position of the rear spar and on the amount of maximum camber. In the aerofoil used it is 3°, so that when the maximum lifting effort is required both fixed and variable planes are operating most efficiently.

It is obvious that under certain conditions—gusts, for example, or flattening out after a steep dive—the wing will be subject to a load greater than its normal maximum. This would be liable to cause further deflection, which would be undesirable. The wing under discussion ceases to deflect after the application of its normal maximum load. This is accomplished by means of an internal bracing system which only comes into operation when the maximum deflection has been reached.

RIB STRUCTURE.

In designing a wing possessing these variable camber features the following considerations had to be kept in mind:

It had to deform regularly with the load up to unit flying load, then remain rigid under further applications of load, and be strong enough to bear several times its normal load without failure. It had also to be capable of easy manufacture, to be simple and foolproof in operation, and light in weight. Metal construction was practically a necessity, and to avoid new features which might be doubtful engineering practice, standard construction was adhered to wherever not essential to the functioning of the device. The ribs were thus the only parts of the wing requiring alteration, leaving spars, bracing wires, struts, etc., substantially as at present. Figure 1 shows the general construction adopted. The essential parts are:

1. Channel-shaped strips *A, B,* forming the upper and lower surfaces of the rib between the spars.

2. Compression links at *C, D, E, F*, and *G*. These are also of channel section and are fixed to the outer channels by pins, thus allowing the necessary angular motion between links and strips.

3. Tension links *H, J, K, L, M,* and *N*. These are flat strips of steel attached to the same pins which carry the compression links. In the stream-line position they carry no load and bow as shown, but in the lifting position they straighten out and make a truss of the rib, preventing further deformation under overloads. The links in the first two and last two panels are slotted to allow the insertion of reverse links.

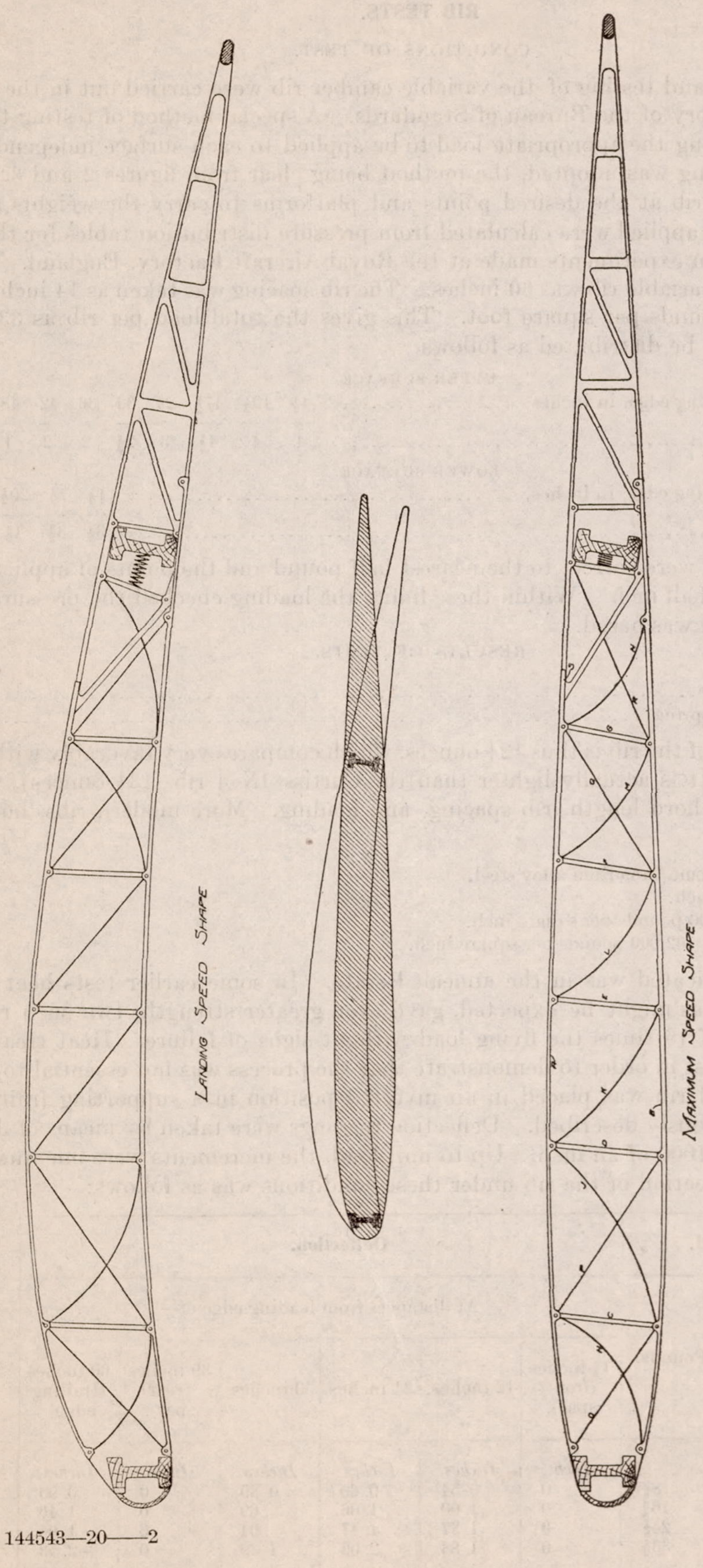
4. Reverse tension links *O, P, Q,* and *R*. The only function of these is to prevent the rib being deformed beyond its stream-line position when subject to loads on the upper surface.

5. A tailpiece, fixed in shape, riveted to the upper strip at *S* and constructed to slide over the rear spar.

6. A spring placed between the rear spar and the tailpiece. Provided the channels *A* and *B* are made of sufficient size, a rib can be made which will function properly without this spring, but its use effects a considerable saving in the total weight of the rib. The spring used is a helical tension spring attached to the rear spar and to the front compression member of the tailpiece.

The upper and lower surfaces are fixed to the front spar, which is placed practically at the leading edge. A light wooden nose piece running the length of the wing and attached to the spar gives a fair shape to the leading edge. The rigidity of the rib, due to the stiffness of the channels and the spring, must be such that it attains its full lifting form under normal flying load. The lengths of the tension links determine the final contour of the wing.

The fabric is continuous over the wings except where the lower flexible channel is connected to the tailpiece. Here it is discontinuous to permit the sliding forward of the fixed tail portion over the end of the channel forming the flexible portion of the lower surface. The amount of this sliding motion is approximately 1 inch, and it may be provided for either by allowing the surface to overlap or simply by leaving a gap of this amount. In the former case the surfaces would just meet when in the stream-line position and would overlap 1 inch in the lifting position. In the latter case they would meet when in the lifting position but in the stream-line position would leave open a strip 1 inch wide running the length of the wing. It is not believed that this would be as objectionable as might appear at first sight, for the aerodynamic properties of the wing would not be appreciably affected. Present methods may be used for its attachment to the ribs. It will probably be preferable to stitch the fabric to each surface separately, though there is no objection to the stitching going over the top and under the bottom, except at the rear spar, as the distances between the surfaces do not alter. It was necessary to determine whether any excessive stretch in the fabric would be caused by the functioning of the ribs. The lower surface changes from a convex to a concave shape of approximately equal curvature. There will, therefore, be no stretch in the fabric. In the upper surface, however, where an increase of convex curvature occurs, there will be a stretch caused in the fabric. Calculation shows that this is not serious. In a wing of 60-inch chord, with a maximum increase of camber of $2\frac{1}{2}$ inches, the maximum stretch of the fabric is only 1/100 inch in the 15 inches in which the greatest change occurs, or 0.067 per cent. As the stretch at rupture is 15 per cent, the fabric is only strained 1/225 of this amount. It is reasonable to suppose that this could be repeated indefinitely.



VARIABLE CAMBER RIB

FIG. 1.

144543—20——2

RIB TESTS.

CONDITIONS OF TEST.

The construction and testing of the variable camber rib were carried out in the Engineering Materials Laboratory of the Bureau of Standards. A special method of testing the rib had to be devised, permitting the appropriate load to be applied to each surface independently. A direct system of loading was adopted, the method being clear from figures 2 and 3. Stirrups were placed over the rib at the desired points and platforms to carry the weights suspended therefrom. The loads applied were calculated from pressure distribution tables for the R. A. F. 14 wing, obtained from experiments made at the Royal Aircraft Factory, England.

The chord of the variable rib was 60 inches. The rib spacing was taken as 14 inches and the wing loading as 5⅝ pounds per square foot. This gives the total load per rib as 33½ pounds, which was assumed to be distributed as follows:

UPPER SURFACE.

Distance from leading edge, in inches	4½	10½	17½	24	30	36	42	48	54
Load, in pounds	4	4	4½	3	2½	2	2	1	1

LOWER SURFACE.

Distance from leading edge, in inches	1½	7½	20½	33
Load, in pounds	3½	3½	1½	1

The applied loads were correct to the nearest half pound and the points of application were correct to the nearest half inch. Within these limits the loading checked the pressure distribution figures on which it was based.

RESULTS OF TESTS.

	Ounces.
Weight of rib, bare	11½
Weight of helical spring	¾

The total weight of the rib is thus 12¼ ounces, which compares very favorably with standard wood construction. It is actually lighter than the Curtiss JN-4 rib (13½ ounces), which was taken as a basis for chord length, rib spacing, and loading. More modern ribs, however, are somewhat lighter.

Material used, chrome vanadium alloy steel.
Thickness, 0.018 inch.
Elastic limit, 90,000 pounds per square inch.
Ultimate strength, 102,000 pounds per square inch.

The steel as fabricated was in the annealed state. In some earlier tests heat treatment was resorted to, and, as might be expected, gave even greater strength, two such ribs having sustained a loading of 16 times the flying load without signs of failure. Heat treatment was omitted in the final test in order to demonstrate that the process was not essential to success.

The experimental rib was placed in an inverted position in a supporting frame and the loads applied as previously described. Deflection readings were taken by means of dials giving readings correct to 1/1000 of an inch. Up to unit load, the increments were one-quarter of the flying load. The deflection of the rib under these conditions was as follows:

Load.		Deflection.					
		At distances from leading edge of—					
Portion of normal flying load.	Pounds.	1½-inches (front spar).	12 inches.	21 inches.	30 inches.	39 inches (rear spar).	60 inches (trailing edge).
		Inch.	*Inches.*	*Inches.*	*Inches.*	*Inch.*	*Inches.*
¼	8⅜	0	0.54	0.60	0.39	0	−0.90
½	16¾	0	1.00	1.06	.69	0	−1.46
¾	25⅛	0	1.37	1.47	.94	0	−1.94
1	33½	0	1.83	2.03	1.39	0	−2.53

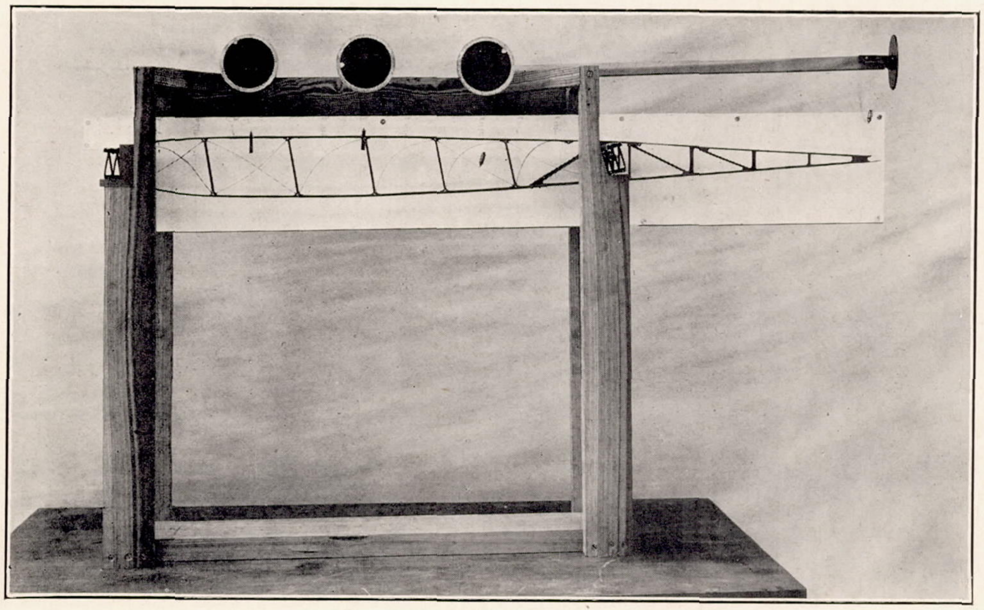


Fig. 2.

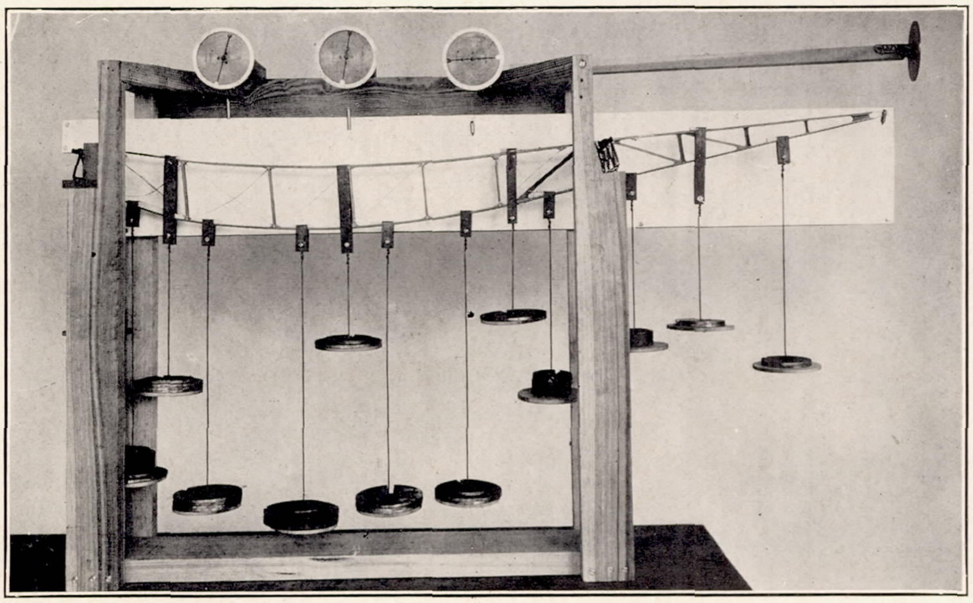


Fig. 3.

Weights were then applied up to six times the flying load. After this the loading was removed, with the exception of the one-quarter load, to determine the ability of the rib to return to its original shape after severe overloads. A permanent set amounting to a maximum of $\frac{5}{32}$ inch occurred in the first and second panels. Throughout the rest of its length the rib returned to the position occupied under the initial one-quarter load.

Finally the rib was loaded to destruction. Failure occurred after the application of a load corresponding to 11 times the flying load by buckling of the flanges of the lower surface in the

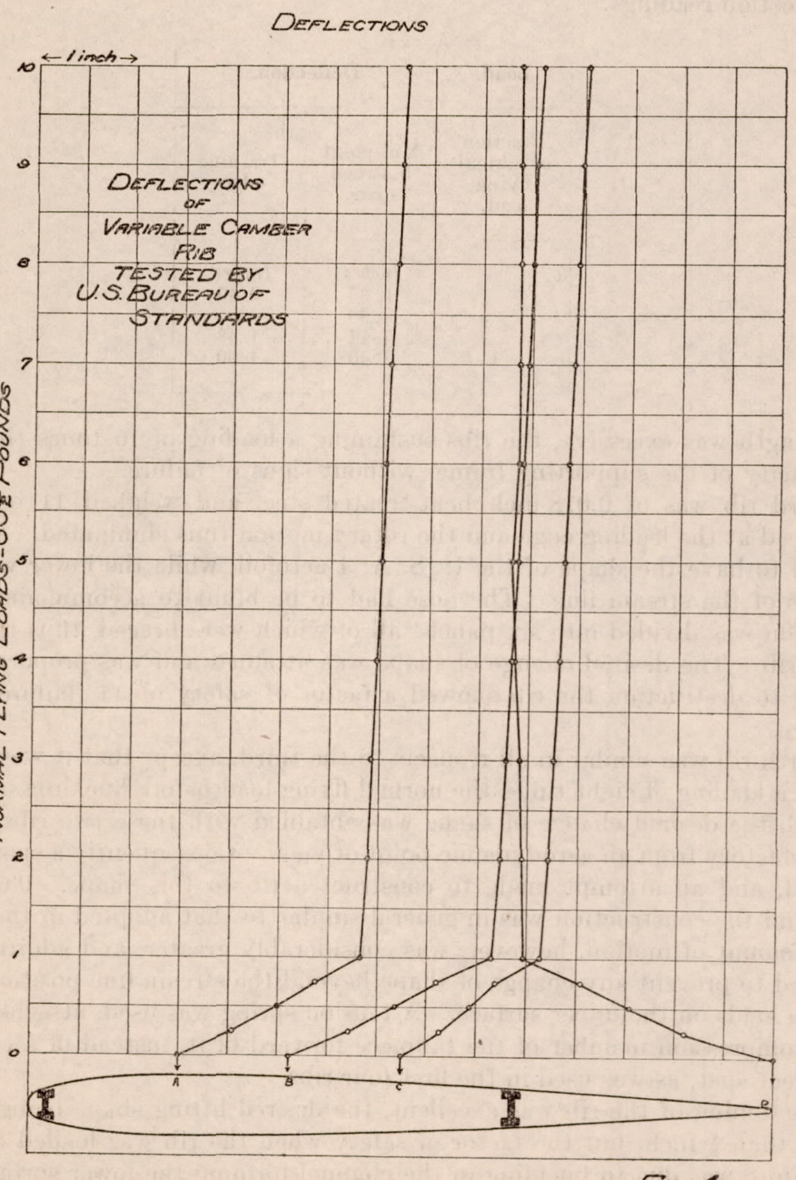


Fig. 4

first and second panels. Deflections are plotted in figure 4 and tabulated in the appendix. The maximum deflection from normal flying load to 10 times that load was 0.437 inch, which compares favorably with that of wooden ribs under similar loads. While subject to the normal flying load, the shape of the rib was traced upon a board placed behind it. Its form agreed (within $\frac{1}{8}$ inch) with the designed aerofoil (V. C. L., fig. 6).

The rib which gave these results was the last of a series of six. It is not claimed that it represents the best possible form for such a rib, but marks a point in the development where the many conflicting requirements are all satisfied.

The first two ribs of the series were made from steel 0.032 inch in thickness and were heat treated. The lifting shape aimed at was the Eiffel 36-wing curve. The spars were placed in the same positions as in the Curtiss JN–4 and the nose was designed to rotate about the front spar. The variable portion was divided into four panels, of which three only were provided with tension-bracing members. The weight was 16 ounces. A change of shape approximately proportional to the load was obtained, but the tail failed to deflect its full amount and the rotary motion at the nose was found unsatisfactory. The functioning of the rib is shown by the following deflection readings:

Load.	**Deflection.**	
Fraction of normal flying load.	Mid-point between spars.	Training edge.
	Inches.	*Inches.*
$\frac{1}{4}$	0.35	0.40
$\frac{1}{2}$	.80	.95
$\frac{3}{4}$	1.14	1.48
1	1.40	1.90

The strength was excessive, the ribs sustaining a loading of 16 times the flying load, the limiting capacity of the supporting frame, without signs of failure.

The third rib was of 0.018-inch heat-treated steel and weighed 11 ounces. The front spar was placed at the leading edge and the rotary motion thus eliminated. The upper surface was designed to have the shape of the U. S. A. 4 aerofoil, while the lower was determined by the thickness of the stream line. The nose had to be blunt to accommodate the spar. The flexible portion was divided into six panels, all of which were braced, thus making a complete truss of the rib. The desired change of shape was attained and was proportional to the load. When tested to destruction the rib showed a factor of safety of 11, failure occurring in the fixed tailpiece.

The fourth rib was similar in all respects to the third, except that it was not heat treated. It withstood a loading of eight times the normal flying load before buckling over sideways.

Although the desired change of shape was obtained with these two ribs, the lifting shape was not satisfactory from an aerodynamic point of view. Consequently a special lifting aerofoil was designed, and an attempt made to construct a rib to this shape. 0.018-inch steel was again used and the construction was in general similar to that adopted in the third and fourth ribs. The amount of motion, however, was considerably greater, and additional tension links were provided to prevent any change of shape beyond the stream-line position should the wing be subject to loads on the upper surface. A tension spring was used, attached to the rear spar and to the compression member of the tailpiece forward of it, instead of a compression spring behind the rear spar, as was used in the first four ribs.

The functioning of the rib was excellent, the desired lifting shape being assumed with an error of less than $\frac{1}{8}$ inch, but the factor of safety when the rib was loaded to destruction was only 7. Failure was due to buckling in the channel forming the lower surface in the first and second panels. The weight was 12 ounces.

The behavior of this rib under fractional loads was as follows:

Load.		Deflection.					
		At distance from leading edge of—					
Portion of normal flying load.	Pounds.	$1\frac{1}{2}$ inches (front spar).	12 inches.	21 inches.	30 inches.	39 inches (rear spar).	60 inches (trailing edge).
		Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
$\frac{1}{4}$	$8\frac{3}{8}$	0	0.45	0.42	0.20	0	−0.45
$\frac{1}{2}$	$16\frac{3}{4}$	0	.99	1.02	.57	0	−1.20
$\frac{3}{4}$	$25\frac{1}{8}$	0	1.44	1.55	.95	0	−1.82
1	$33\frac{1}{2}$	0	1.82	1.98	1.25	0	−2.42

The final rib differed only in minor details, particularly the use of a heavier flange at the point of failure. This raised the factor of safety from 7 to 11 at an increase of only $\frac{1}{4}$ ounce in weight.

AERODYNAMICAL TESTS.

A series of tests were carried out by the Bureau of Standards wind tunnel staff to determine the following points:

1. The properties of four new aerofoils, being the stream-line and full-lifting shapes of the variable camber wing, and two intermediate shapes under one-third load and two-thirds load, respectively.
2. The aerodynamic efficiency of these aerofoils when used together with a standard aerofoil in biplane and triplane combinations.
3. The stability of these biplane and triplane combinations.

Models of the necessary aerofoils were made of bakelite and were correct to within five one-thousandths of an inch. The model of R. A. F. 6, which was used as the standard section, was of wood, and though accurate when made did not retain its accuracy as well as the bakelite models.

The stream-line and full-lifting aerofoils were designed in accordance with certain limitations imposed by the rib structure. The chief of these were:

1. The necessity for a blunt nose to permit the front spar being placed at the leading edge.
2. In the lifting model a lower surface concave toward the trailing edge could not be used because the portion of the rib behind the rear spar does not change shape and the stream line is slightly convex.
3. The camber of the lower surface between the spars was limited by the necessity of allowing for internal bracing wires.
4. The maximum camber on the upper surface was determined by the camber of the lower and by the thickness of the aerofoil, which, in turn, was determined by the fineness desired in the stream line.

The two extreme shapes were carefully designed in the light of these and of aerodynamical considerations. The intermediate shapes were obtained on the assumption that the rib deflected throughout its length directly as the load up to normal full load. Control can be exercised over the design of these intermediate shapes by varying the depth of the flanges of the rib channels, but as the distribution of pressure is also a factor and as it is not known how much the distribution assumed (R. A. F. 14) differs from the actual, the shapes used were arrived at somewhat arbitrarily.

The wind tunnel used at the Bureau of Standards is of 54-inch octagonal section, the air being drawn through by a 100-horsepower motor. The balance is of the N. P. L. type and the models were mounted vertically in the tunnel. In the biplane and triplane combinations the models were spaced relatively by brass struts screwed into the ends. Provision was made for a fine adjustment of the decalage by the arrangement illustrated in figure 7. The points of attachment of the struts to the variable planes corresponded approximately with the positions of the spars in the full-size wing. The leading edge was thus fixed in position, so no adjustment for gap was necessary. The chord of the fixed middle aerofoil was used as a reference plane, and the decalage measured by the difference in gap at the trailing edge.

Lift, drag, and torque determinations were carried out on the following aerofoils and combinations:

Aerofoil V. C. stream line (*a*) used afterwards in biplane and triplane tests; V. C. stream line (*b*) used in triplane tests only.

Aerofoil V. C. one-third lifting (*a*) used in biplanes and triplanes; V. C. one-third lifting (*b*) used in triplanes only.

Aerofoil V. C. two-thirds lifting, used in biplane tests.

Aerofoil V. C. lifting (*a*) used in triplanes and biplanes; (*b*) used in triplanes only.

Aerofoil R. A. F. 6, used in biplanes and triplanes.

Biplanes.

No.	Lower plane.	Upper plane.	Stagger.	Decalage.
			Per cent.	*Degrees.*
1	R. A. F. 6	V. C. S	−20	$2\frac{1}{2}$
2	R. A. F. 6	V. C. $\frac{1}{3}$ L	−20	$1\frac{1}{2}$
3	R. A. F. 6	V. C. $\frac{2}{3}$ L	−20	$\frac{1}{2}$
4	R. A. F. 6	V. C. L	−20	$-\frac{1}{2}$
5	V. C. S	R. A. F. 6	+20	$2\frac{1}{2}$
6	V. C. $\frac{1}{3}$ L	R. A. F. 6	+20	$1\frac{1}{2}$
7	V. C. $\frac{2}{3}$ L	R. A. F. 6	+20	$\frac{1}{2}$
8	V. C. L	R. A. F. 6	+20	$-\frac{1}{2}$

Triplanes.

No.	Top plane.	Middle plane.	Bottom plane.	Stagger.	Decalage.
				Per cent.	*Degrees.*
1	V. C. S	R. A. F. 6	V. C. S	20	$2\frac{1}{2}$
2	V. C. $\frac{1}{3}$ L	R. A. F. 6	V. C. $\frac{1}{3}$ L	20	$1\frac{1}{2}$
3	Test—not run				
4	V. C. L	R. A. F. 6	V. C. L	20	$-\frac{1}{2}$

The term decalage here refers to the incidence of the planes of the variable series to the chord line of the standard plane.

Detailed results will be found tabulated in the appendix at the end of the report.

DISCUSSION OF WIND-TUNNEL RESULTS.

SINGLE AEROFOILS.

The curves for the variable wing as a monoplane (fig. 8) were obtained from figures 14, 15, and 16. At low angles ($-3°$, $-2°$, $-1°$, $0°$), when the variable wing was stream line, the points for the variable curves were obtained from the curves for V. C. S. At high angles (12°, 14°, 16°, 17°, 18°), when it was in its full lifting shape, the points from V. C. L. were used. Two intermediate sets of points were obtained—one from the curve for V. C. $\frac{1}{3}$ L. at 4° and the other from the V. C. $\frac{2}{3}$ L. curves at 8°.

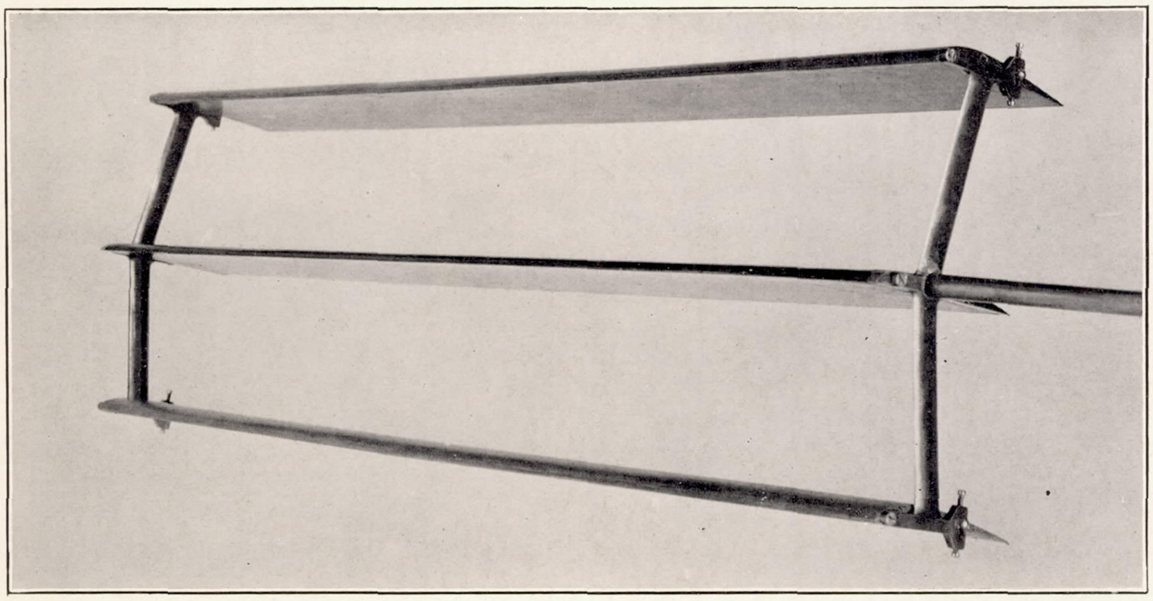


Fig. 7.

The travel of the center of pressure is noteworthy, being as nearly as possible stationary—the amount of travel within the range of flying angles being 0.035 chord in the stable direction. Aerofoils of the fixed type are unstable. Thus, if the center of pressure coincides with the center of gravity at any angle within the flying range, the plane will be in equilibrium. If, however, it is then displaced from this angle, the position of the center of pressure will change and will introduce an upsetting moment which will move the plane still further from its position of equilibrium. This unstable effect is very marked at small angles of incidence. This is apparent from figure 16, the curves for V. C. $\frac{1}{3}$ L., V. C. $\frac{2}{3}$ L., and V. C. L. being typical of all ordinary aerofoils. In figure 8 the motion of the center of pressure is such that if the plane be displaced from its angle of equilibrium the resulting moment will tend to bring it back to that position. At 17° a marked change occurs, but this is evidently due to the breakdown in the air flow which takes place at that angle, and which is also noticeable in the lift and drag curves. The individual curves (figs. 14, 15, and 16) are characteristic for the particular types of aerofoils, though the intermediate shapes are somewhat inefficient when compared with other aerofoils of similar camber.

The drag curve (fig. 15) shows that the minimum resistance of the stream-line plane is less than one-third that of the lifting plane. These are the figures for the models at the tunnel speed of 50 miles per hour. In a full-size machine, traveling at 150 miles per hour, the minimum drag would be about one-quarter. This improvement at high speed is due to the fact that the drag of an aerofoil is made up of two parts—the direct head resistance, which increases as the square of the speed, and the skin friction, which increases at a lesser rate. The drag of a stream-line body is mostly skin friction, while that of a heavily-cambered aerofoil is nearly all direct head resistance. Variable camber, therefore, gives us a wing having the high lift coefficient of V. C. L. with the objectionable high minimum drag of such a wing cut down by 75 per cent.

BIPLANES.

The first biplane series, with the variable wing for the upper plane and with the negative stagger, shows excessive stability. The vector diagram (fig. 11) was obtained by assuming a center of pressure travel by plotting a curve through the appropriate points in figure 19. Up to $2\frac{1}{2}$° the variable plane is stream line, at $4\frac{1}{2}$° it is assumed to be one-third lifting, at 8° to be two-thirds lifting, and 12° to be full lifting.

If the planes were attached to the machine so that the center of gravity was situated at a point on the vector for 2°, and slightly above the lower plane, the arrangement would be stable under all conditions. Thus, if the incidence was increased to 18°, a moment would come into play tending to reduce the incidence, while if it was reduced to 0°, the resulting moment would cause it to be increased. Even in the abnormal position represented by the vector for -1° there would still be a correcting moment to bring the machine back to its position of equilibrium. The stability in the case of this biplane is excessive by reason of the correcting moment being too great. There seems no reason why a more satisfactory arrangement should not be obtained with a stagger of 10 or 15 per cent. Forward stagger with this combination, however, would cause very serious instability, as would back stagger in the second biplane arrangement.

This second series, with the lower plane the variable one, and the top plane staggered 20 per cent forward, is very satisfactory. The vector diagram (fig. 12) shows sufficient but not excessive stability, with all the vectors passing practically through a point midway between the planes. The lift curves (fig. 20) are regular, and show no serious falling off at the burble point. No. 8, which is the landing-speed combination, is particularly satisfactory in this respect, having a flat top for 6°. Even after 20°, where the flow does not break down, there is a complete absence of the abrupt change which is apparent in the curve for the variable wing as a monoplane. The lift/drag curves (fig. 21) bring out very clearly the advantages of the variation in camber. Thus the combination with the stream-line plane is most efficient at the small values of the lift coefficient appropriate to very high speeds. Maximum lift/drag is obtained at high but not top speeds, with the variable plane one-third lifting, while for climbing speeds the combination containing the two-thirds aerofoil is most efficient. For landing, as would be expected, the curve for the combination with the full lifting wing surpasses all the others. The inefficiency of this high lift combination, should it be used at high speeds, is very apparent.

Figure 9 is derived from the lift/drag against C_y curves in figures 18 and 21. The base used in this case is *speed*, or $\sqrt{\frac{C_y \text{ maximum.}}{C_y}}$ If C_y maximum is 0.56, it is obvious that when C_y is 0.14 the speed will have to be double that at C_y maximum, in order for the machine to remain in level flight. The curves show actual biplane figures for the variable biplanes. For the R. A. F. 6 biplane, however, a correction was applied to the monoplane figures found for the particular model used in all the tests. The biplane corrections used were those given by Dr. Hunsaker. The figures for lift/drag for all the curves have been corrected for scale effect. The assumptions were made on a basis of a maximum speed of 150 miles an hour and a total area of 400 square feet. A figure for the skin friction of the model was obtained from Zahm's equation:

$$F = 0.0000082\ A^{0.93}V^{1.86}$$

This was subtracted from the corrected balance reading for the drag on the model, and a coefficient derived for direct head resistance. The square law was applied to this portion of the drag, and the total drag was obtained by adding to it the skin friction for the full-size planes, again using Zahm's formula. In the light of some recent full-scale experiments this correction is conservative, but the curves nevertheless show a very marked advantage in favor of the suggested arrangement.

TRIPLANE.

The triplane curves show the same general characteristics as the biplane. The arrangement is stable—rather too much so. A 15 per cent setback of the top and bottom planes should give all that is needed in this respect and at the same time would be slightly better structurally.

SUMMARY.

1. The variable camber wing has a maximum lift coefficient of 0.76 (absolute) and a minimum drag of 0.0070. It has a stable travel of the center of pressure of 0.035 of the chord (fig. 8).

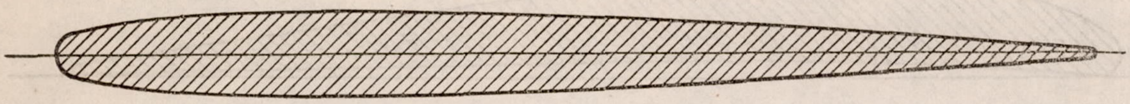
2. At the wind tunnel speed of 30 miles an hour, its minimum drag is less than one-third the minimum drag it would have if the full lifting shape were to be used at small angles of incidence (fig. 15). Under full-size conditions this would be about a quarter.

3. When used in a biplane, the lift/drag is doubled at speeds in excess of 2.1 times the landing speed, and trebled at three times the landing speed. Similar results were obtained in a triplane (figs. 9 and 10).

4. A biplane with 20 per cent forward stagger shows satisfactory stability in the planes themselves. A biplane with 20 per cent back stagger, and a triplane combination, show somewhat excessive stability (figs. 11, 12, and 13).

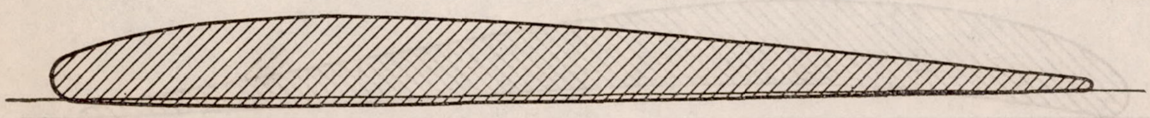
5. The device involves changes in the ribs only.

6. A rib tested at the Bureau of Standards of the same chord length as the Curtiss JN-4, weighed 10 per cent less than that type of rib and showed a factor of safety of 11.



Aerofoil VCS.

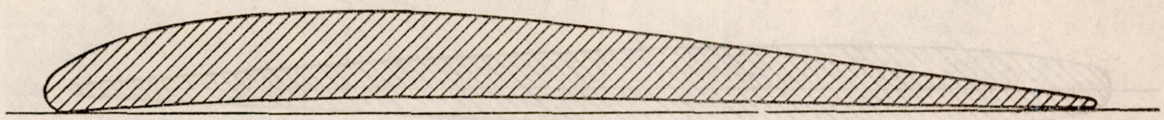
Distance from leading edge.	Length of ordinate.	
	Above chord.	Below chord.
0.00	0.0000	
.05	.0283	
.10	.0358	
.20	.0405	
.30	.0405	
.40	.0377	
.50	.0333	
.60	.0295	
.70	.0236	
.80	.0180	
.90	.0108	
1.00	.0035	



Aerofoil VC½L.

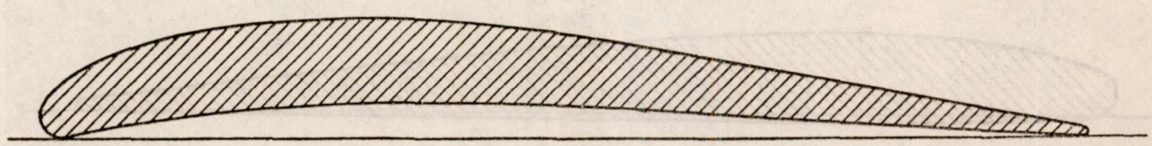
Distance from leading edge.	Ordinates.	
	Upper surface.	Lower surface.
0.000	0.0205	0.0205
.025	.0456	.0000
.050	.0540	.0013
.075	.0600	.0027
.100	.0660	.0037
.200	.0770	.0060
.300	.0773	.0063
.400	.0693	.0056
.500	.0630	.0050
.600	.0546	.0043
.700	.0440	.0037
.800	.0330	.0027
.900	.0304	.0013
1.000	.0070	.0000

FIG. 5



Aerofoil VC$\frac{2}{3}$L.

Distance from leading edge.	Ordinates.	
	Upper surface.	Lower surface.
0. 000	0. 0205	0. 0205
. 025	. 0483	. 0000
. 050	. 0613	. 0021
. 100	. 0773	. 0053
. 200	. 0915	. 0106
. 300	. 0945	. 0153
. 400	. 0897	. 0145
. 500	. 0803	. 0133
. 600	. 0680	. 0096
. 700	. 0543	. 0066
. 800	. 0396	. 0038
. 900	. 0233	. 0019
1. 000	. 0070	. 0000



Aerofoil VCL.

Distance from leading edge.	Ordinates.	
	Upper surface.	Lower surface.
0. 000	0. 0205	0. 0205
. 125	. 0430	. 0017
. 025	. 0543	. 0000
. 050	. 0695	. 0058
. 100	. 0888	. 0152
. 200	. 1068	. 0255
. 300	. 1114	. 0301
. 400	. 1080	. 0316
. 500	. 0966	. 0300
. 600	. 0816	. 0242
. 700	. 0646	. 0173
. 800	. 0466	. 0108
. 900	. 0268	. 0054
1. 000	. 0070	. 0000

FIG. 6.

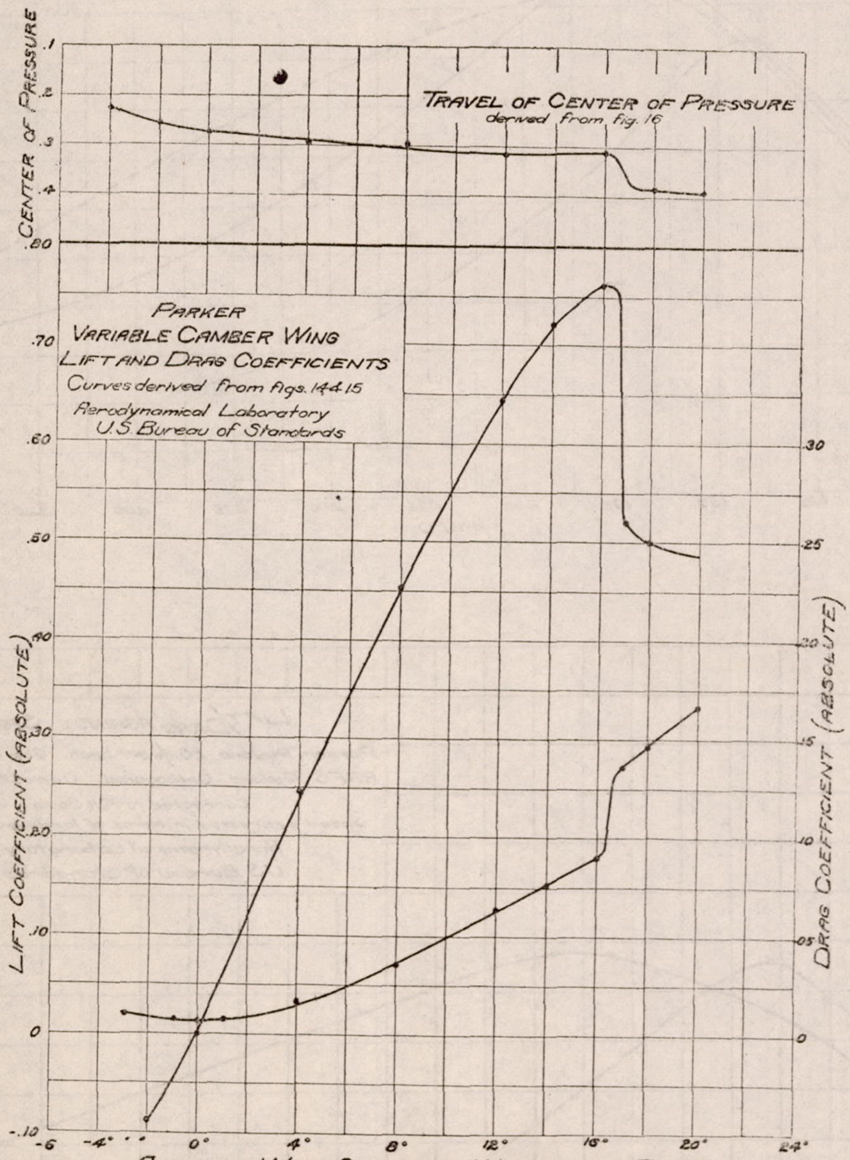


Fig. 8

Plot H vs. V

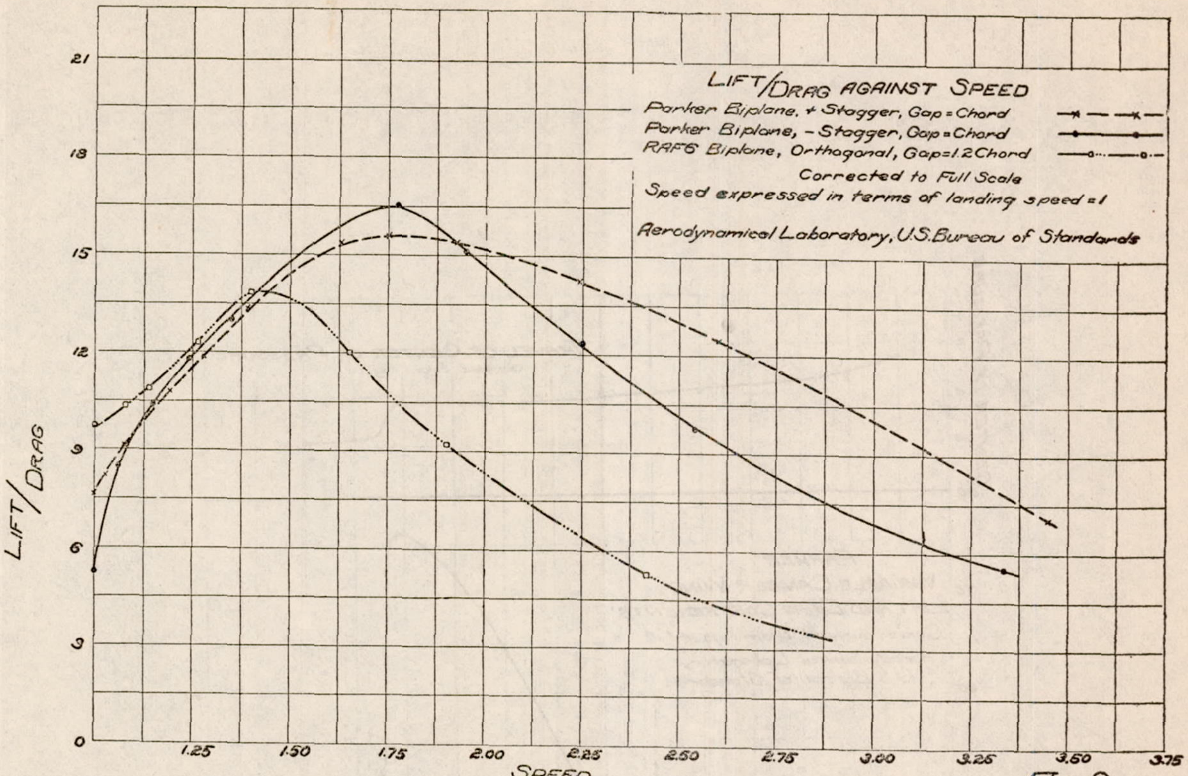

LIFT/DRAG AGAINST SPEED
Parker Biplane, + Stagger, Gap = Chord
Parker Biplane, – Stagger, Gap = Chord
RAF6 Biplane, Orthogonal, Gap=1.2 Chord
Corrected to Full Scale
Speed expressed in terms of landing speed = 1
Aerodynamical Laboratory, U.S. Bureau of Standards
LIFT/DRAG
SPEED
0
3
6
9
12
15
18
21
1.25
1.50
1.75
2.00
2.25
2.50
2.75
3.00
3.25
3.50
3.75

Fig. 9.

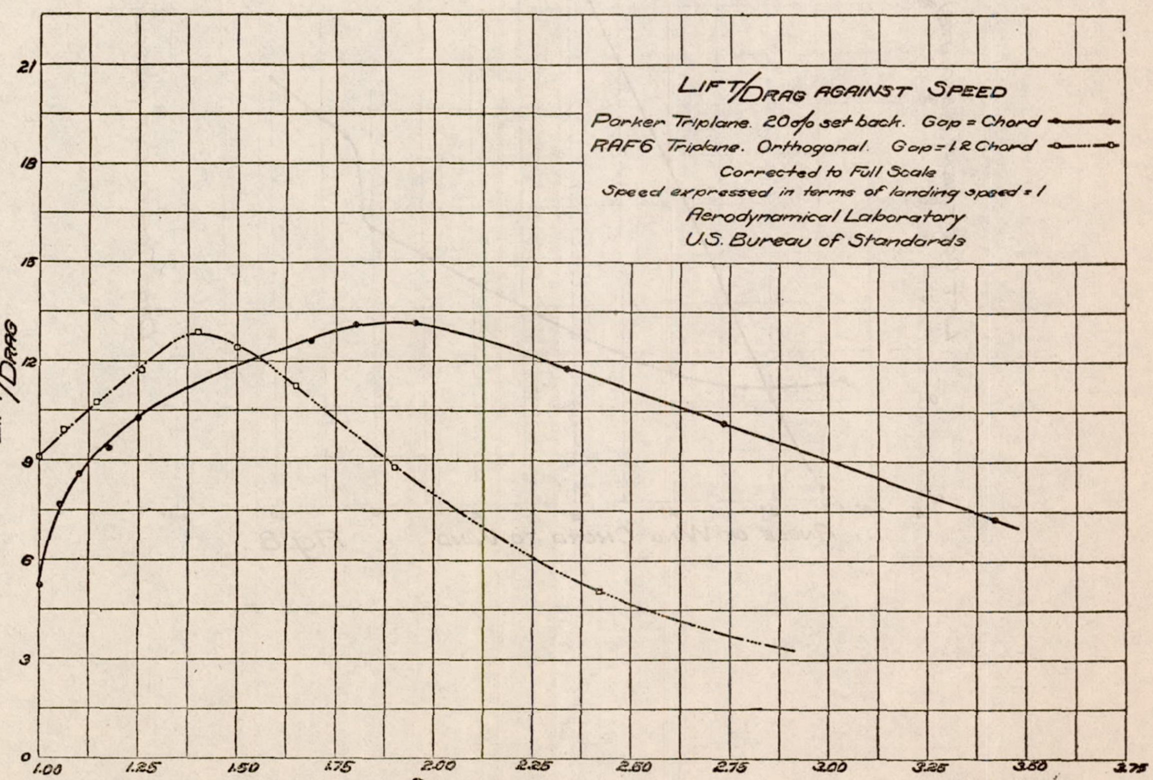

LIFT/DRAG AGAINST SPEED
Parker Triplane. 20% set back. Gap = Chord
RAF6 Triplane. Orthogonal. Gap = 1.2 Chord
Corrected to Full Scale
Speed expressed in terms of landing speed = 1
Aerodynamical Laboratory
U.S. Bureau of Standards
LIFT/DRAG
SPEED
0
3
6
9
12
15
18
21
1.00
1.25
1.50
1.75
2.00
2.25
2.50
2.75
3.00
3.25
3.50
3.75

Fig. 10.

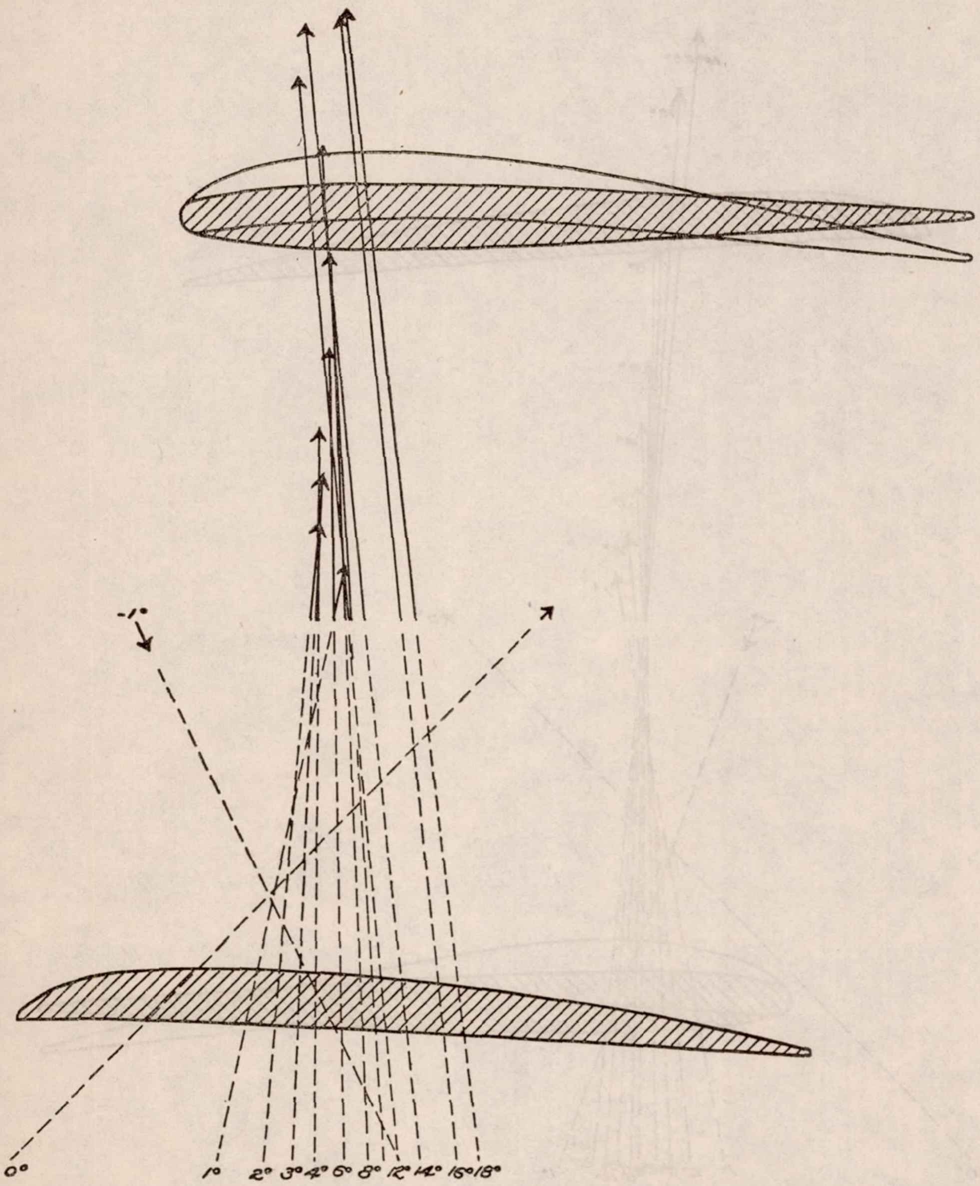


FIG. 11.—Vector diagram for Parker biplane. Upper plane: Variable camber. Lower plane: RAF6. Stagger 20 per cent negative. Gap=chord.

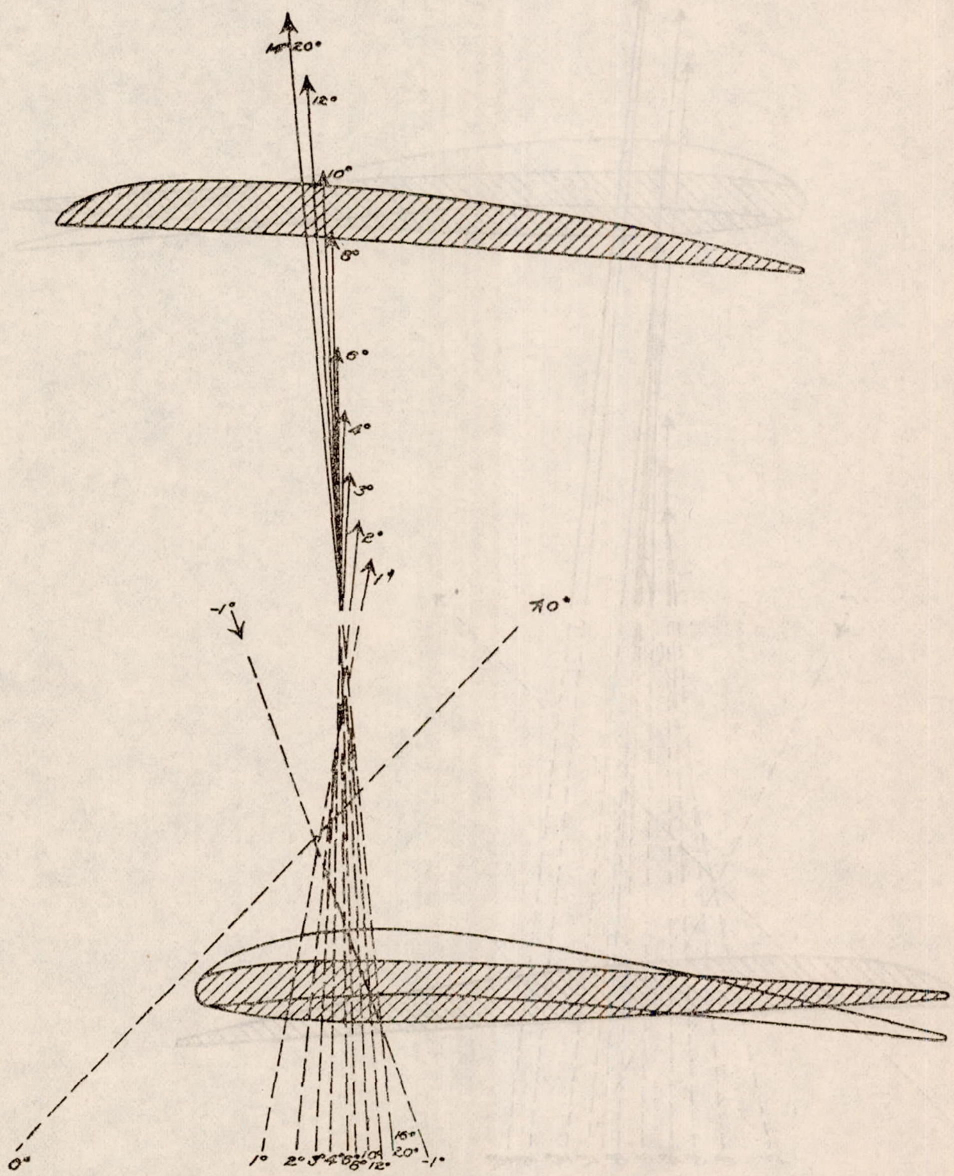


FIG. 12.—Vector diagram for Parker biplane. Upper plane: RAF6. Lower plane: Variable camber. Stagger 2 per cent positive. Gap=chord.

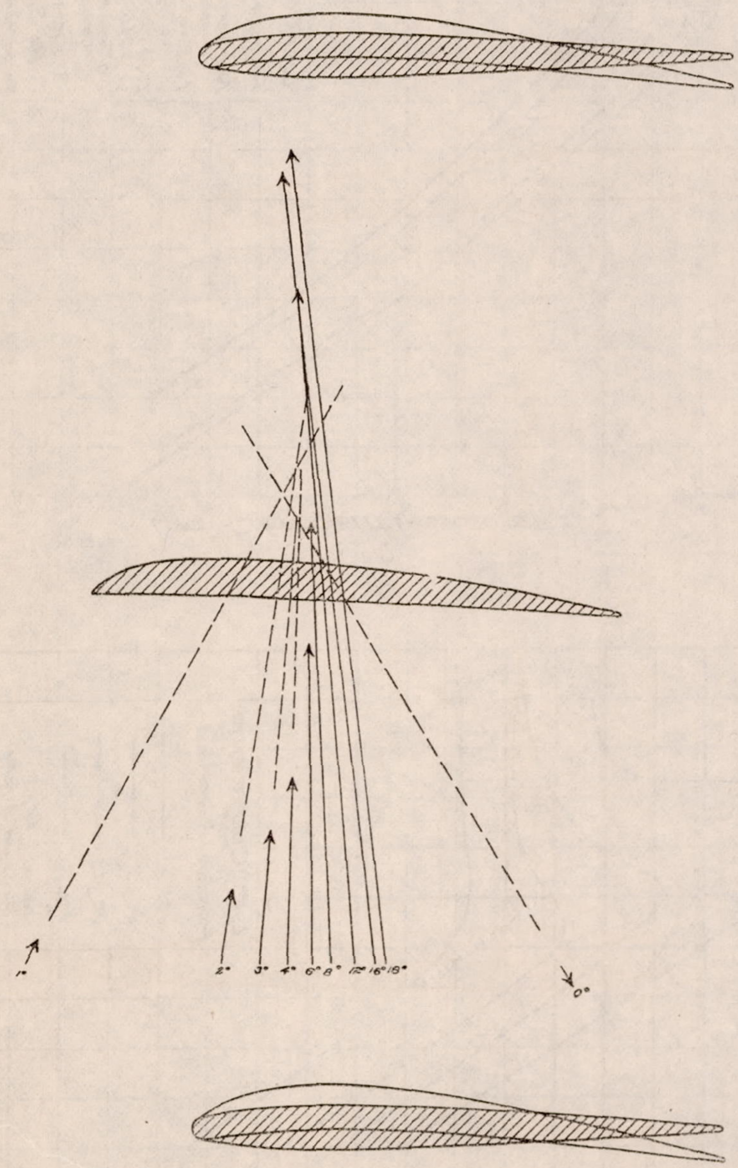


FIG. 13.—Vector diagram for Parker triplane.

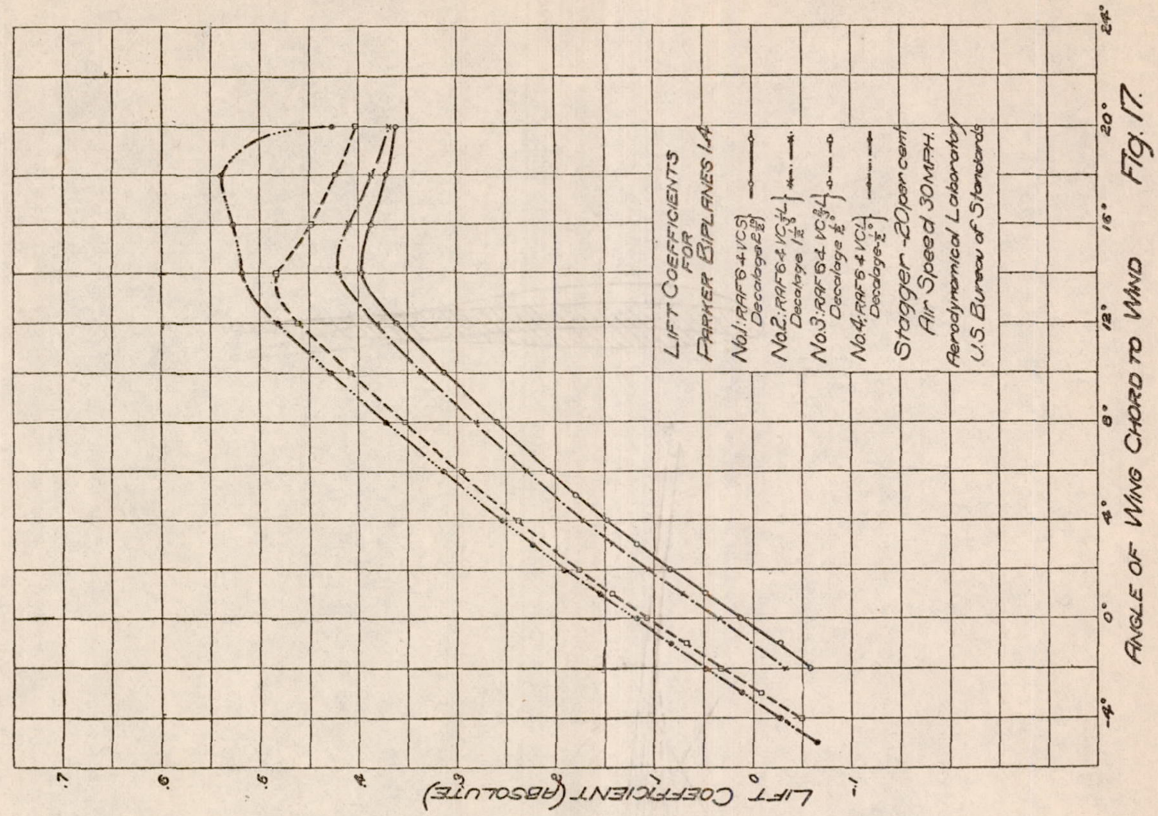

LIFT COEFFICIENTS FOR PARKER BIPLANES 1.4
Stagger -20 per cent
Air Speed 30 M.P.H.
Aerodynamical Laboratory
U.S. Bureau of Standards
ANGLE OF WING CHORD TO WIND
LIFT COEFFICIENT (ABSOLUTE)

Fig. 17.

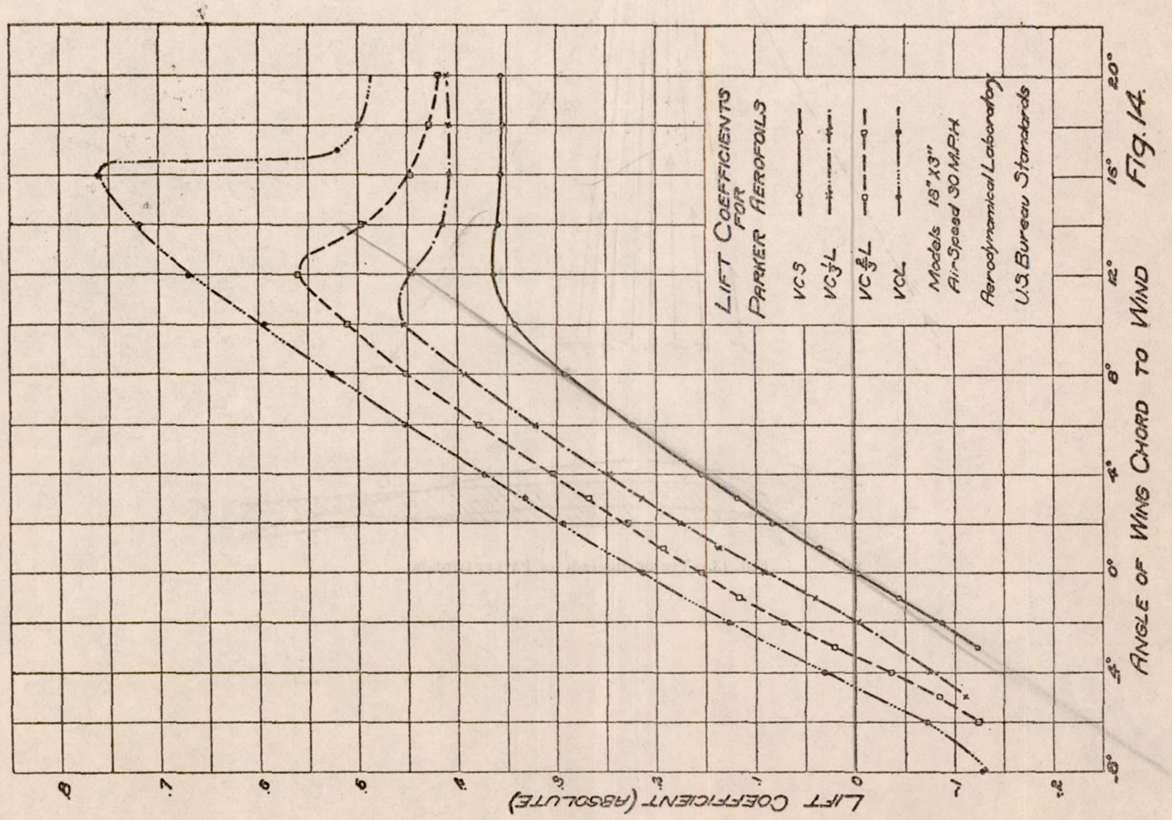

LIFT COEFFICIENTS FOR PARKER AEROFOILS
VCS
VCL
Models 18"X3"
Air-Speed 30 M.P.H.
Aerodynamical Laboratory
U.S. Bureau of Standards
ANGLE OF WING CHORD TO WIND
LIFT COEFFICIENT (ABSOLUTE)

Fig. 14.

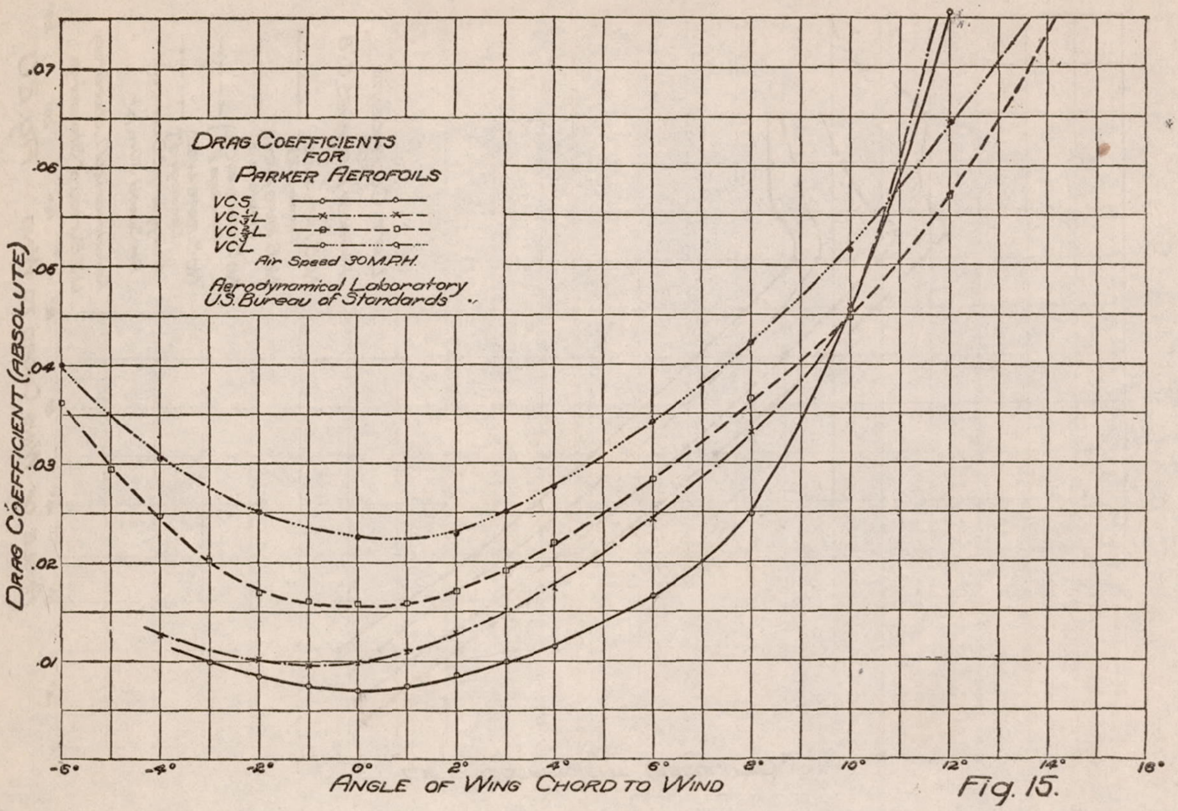

Drag Coefficients
for
Parker Aerofoils
VCS
VC⅓L
VC⅔L
VCL
Air Speed 30 M.P.H.
Aerodynamical Laboratory
U.S. Bureau of Standards
Drag Coefficient (Absolute)
Angle of Wing Chord to Wind

Fig. 15.

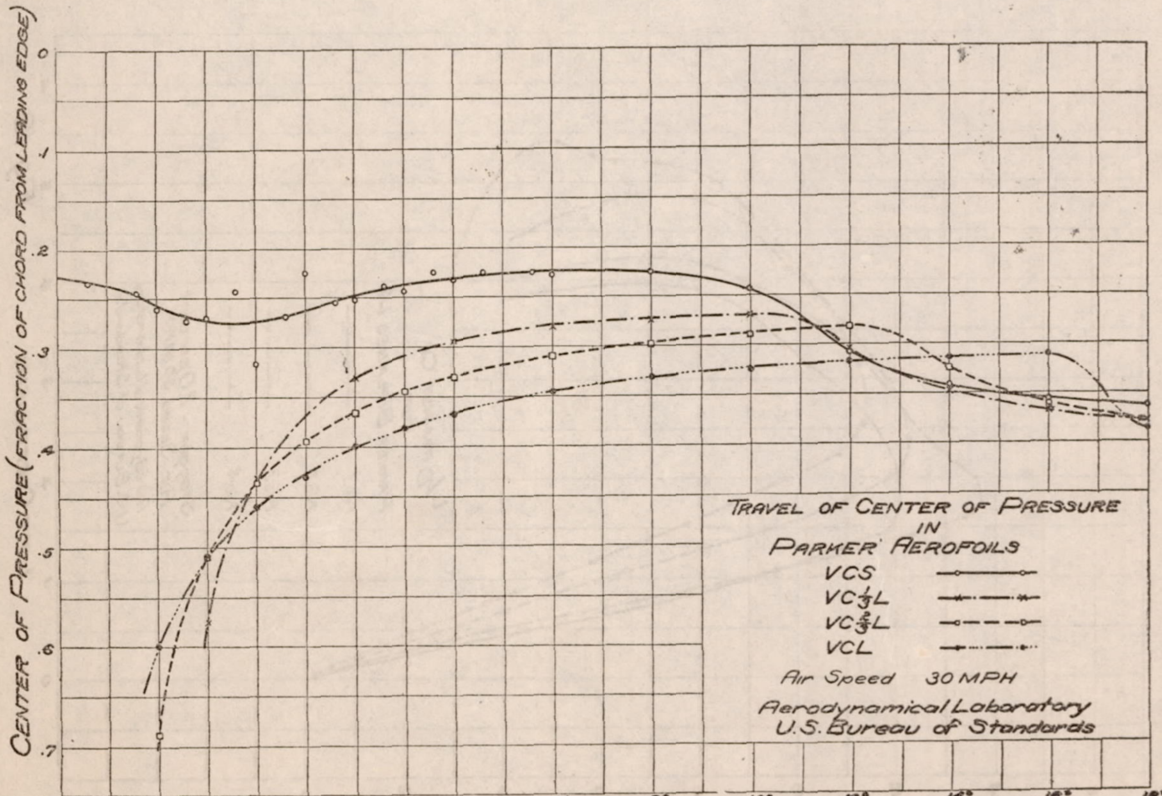

Travel of Center of Pressure
in
Parker Aerofoils
VCS
VC⅓L
VC⅔L
VCL
Air Speed 30 MPH
Aerodynamical Laboratory
U.S. Bureau of Standards
Center of Pressure (fraction of chord from leading edge)
Angle of Wing Chord to Wind

Fig. 16.

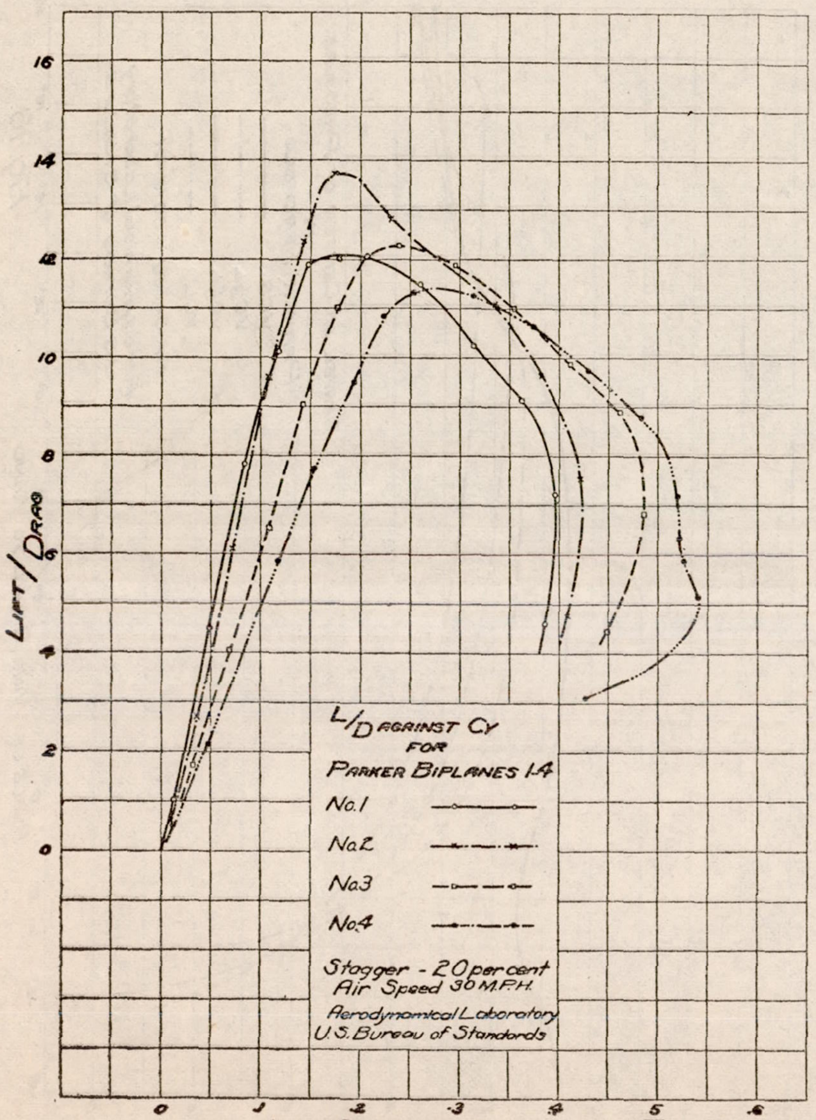

L/D AGAINST CY
FOR
PARKER BIPLANES 1-4
No.1
No.2
No.3
No.4
Stagger - 20 per cent
Air Speed 30 M.P.H.
Aerodynamical Laboratory
U.S. Bureau of Standards
LIFT / DRAG
LIFT COEFFICIENT
0
2
4
6
8
10
12
14
16
0
.1
.2
.3
.4
.5
.6

Fig. 18.

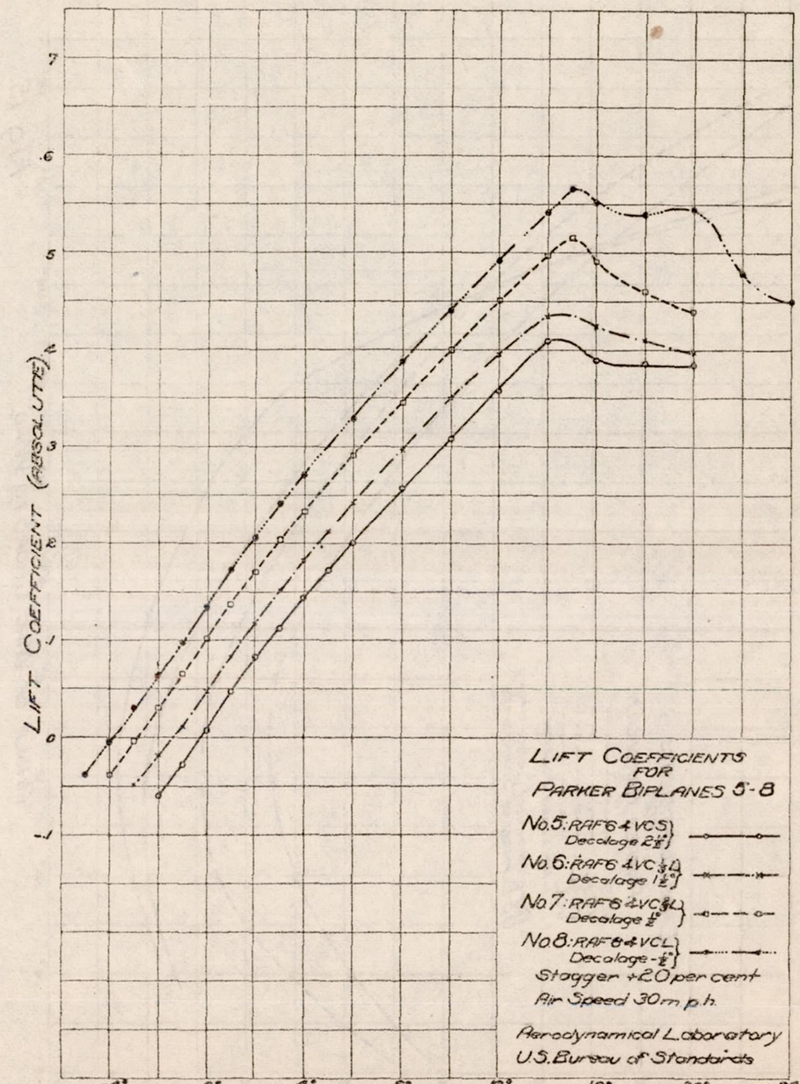
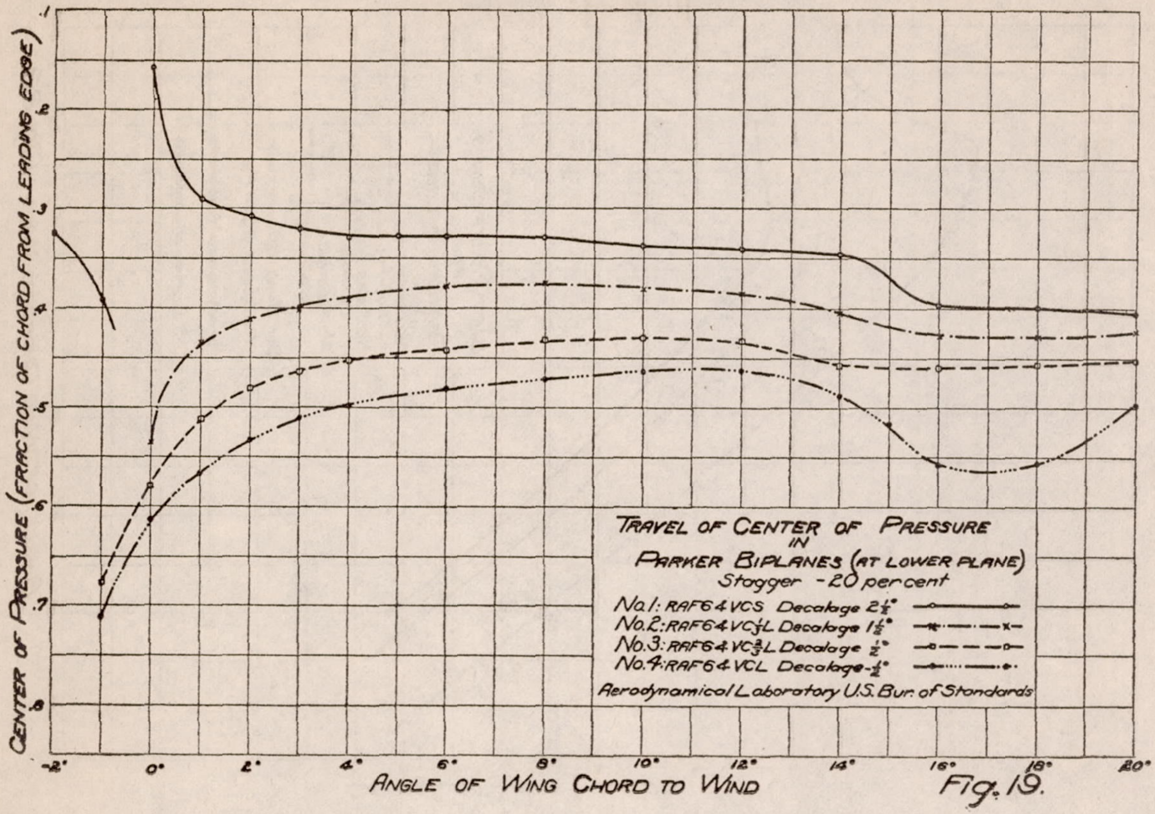
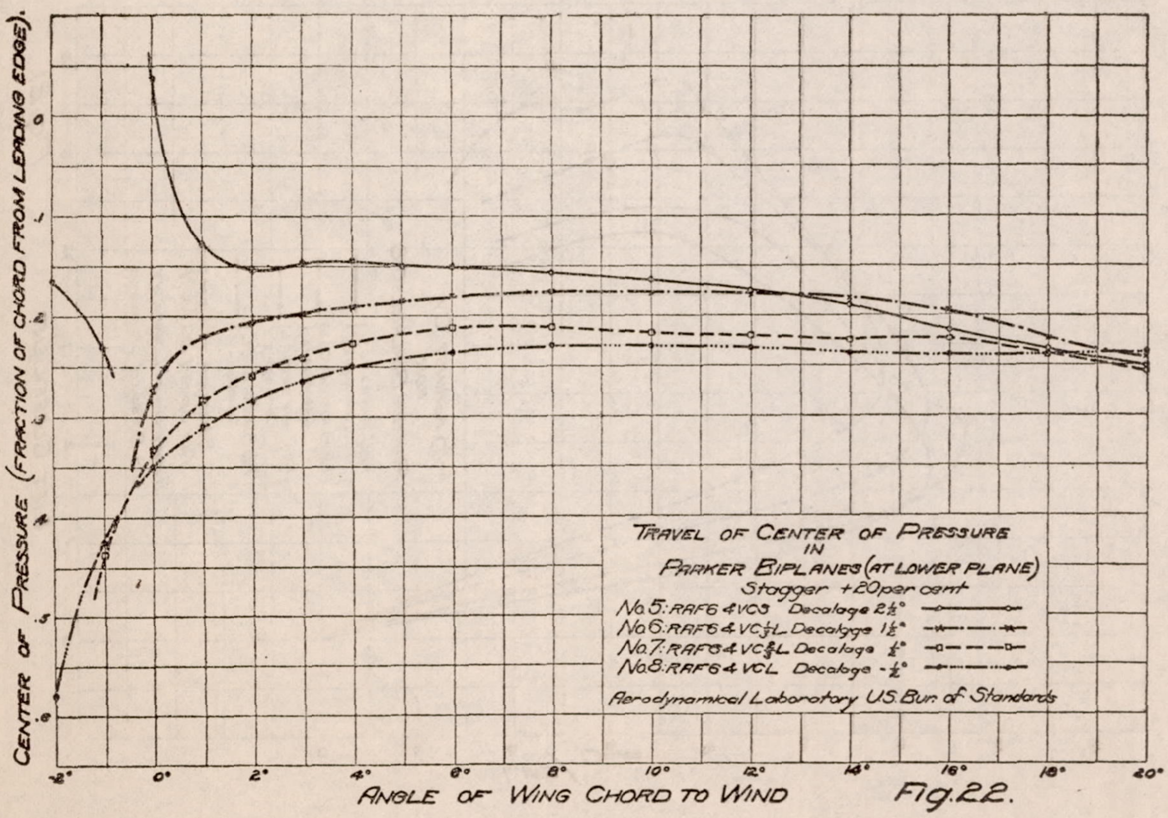

LIFT COEFFICIENTS
FOR
PARKER BIPLANES 5-8
No.5: RAF6 4 VC5 } Decalage 2½°
No.6: RAF6 4 VC¼L } Decalage 1½°
No.7: RAF6 4 VC⅜L } Decalage ½°
No.8: RAF6 4 VCL } Decalage -½°
Stagger +20 per cent
Air Speed 30 m.p.h.
Aerodynamical Laboratory
U.S. Bureau of Standards
LIFT COEFFICIENT (ABSOLUTE)
ANGLE OF WING CHORD TO WIND
-.1
0
.1
.2
.3
.4
.5
.6
.7
-4°
0°
4°
8°
12°
16°
20°
24°

Fig. 20



Travel of Center of Pressure in Parker Biplanes (at lower plane)
Stagger -20 percent
No.1: RAF64VCS Decalage 2½°
No.2: RAF64VC⅓L Decalage 1½°
No.3: RAF64VC⅔L Decalage ½°
No.4: RAF64VCL Decalage -½°
Aerodynamical Laboratory U.S. Bur. of Standards
Center of Pressure (fraction of chord from leading edge)
Angle of Wing Chord to Wind

Fig. 19.



Travel of Center of Pressure in Parker Biplanes (at lower plane)
Stagger +20 per cent
No.5: RAF64VCS Decalage 2½°
No.6: RAF64VC⅓L Decalage 1½°
No.7: RAF64VC⅔L Decalage ½°
No.8: RAF64VCL Decalage -½°
Aerodynamical Laboratory U.S. Bur. of Standards
Center of Pressure (fraction of chord from leading edge).
Angle of Wing Chord to Wind

Fig. 22.

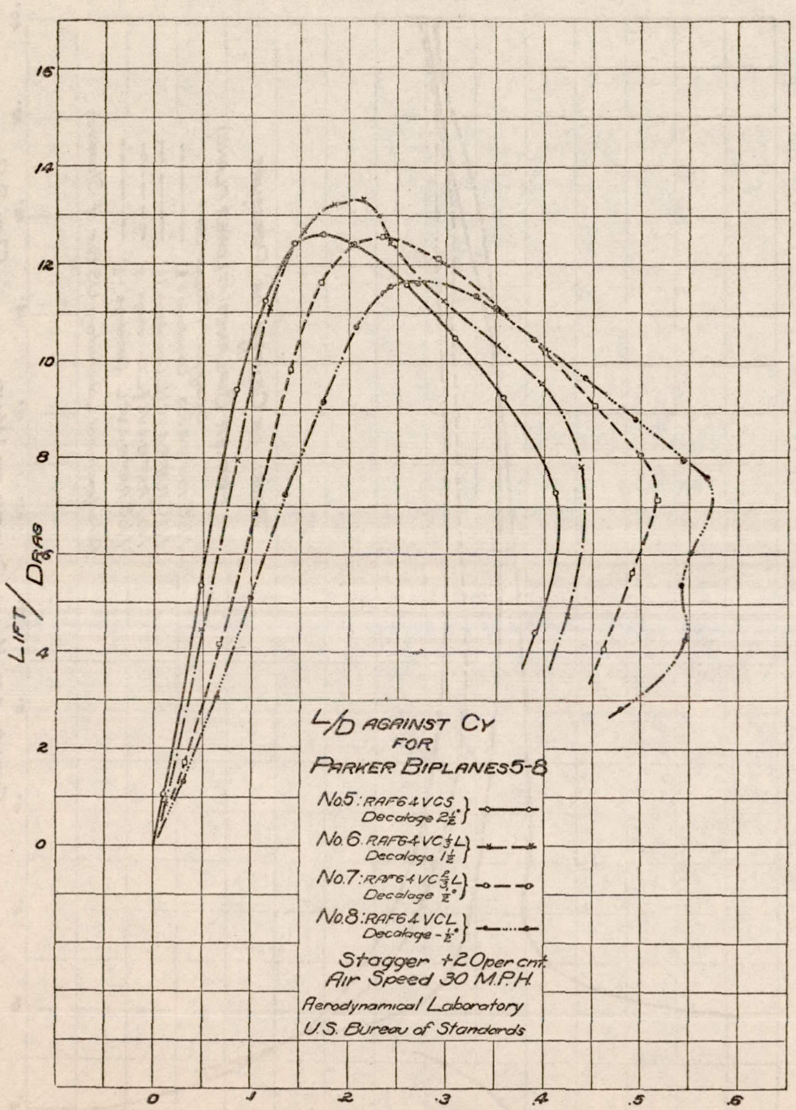

LIFT / DRAG
L/D AGAINST CY
FOR
PARKER BIPLANES 5-8
No.5: RAF 6 4 VCS Decalage 2½°
No.6. RAF 6 4 VC⅓L Decalage 1½°
No.7: RAF 6 4 VC⅔L Decalage ½°
No.8: RAF 6 4 VCL Decalage -½°
Stagger +20 per cnt.
Air Speed 30 M.P.H.
Aerodynamical Laboratory
U.S. Bureau of Standards
LIFT COEFFICIENT

Fig. 21.

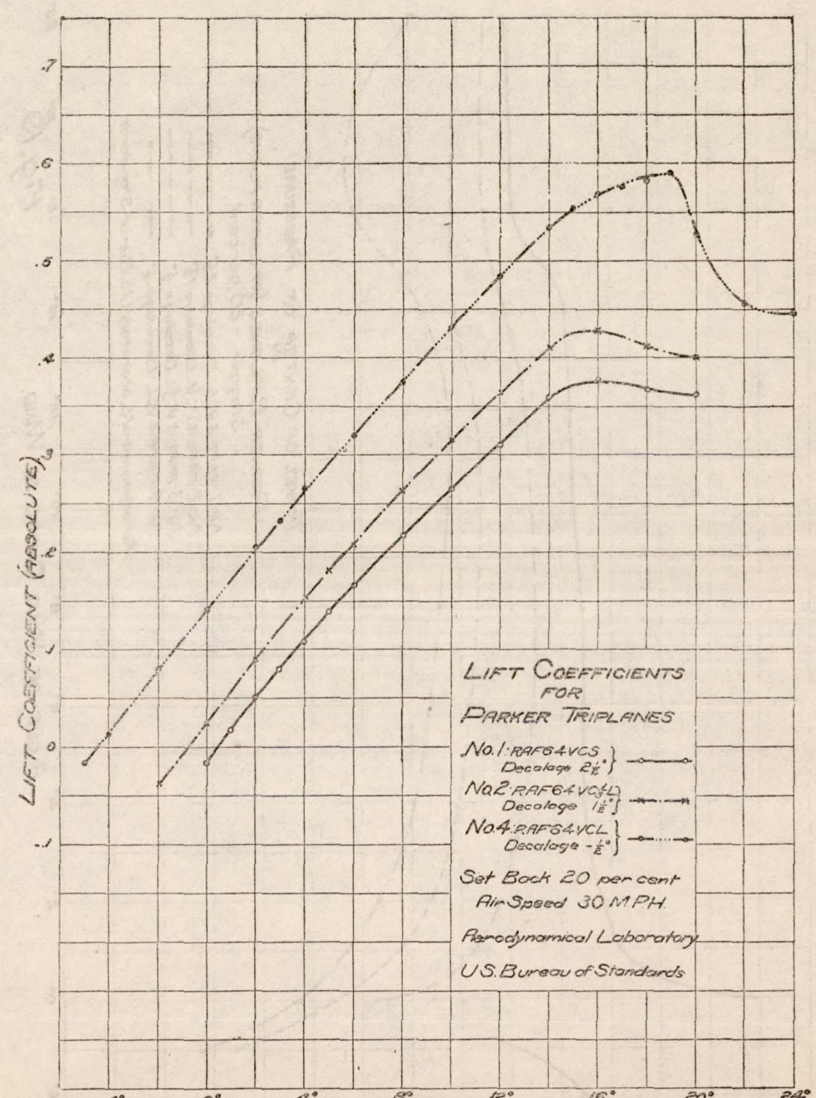

LIFT COEFFICIENT (ABSOLUTE)
LIFT COEFFICIENTS
FOR
PARKER TRIPLANES
No.1: RAF 6 4 VCS Decalage 2½°
No.2: RAF 6 4 VC⅓L Decalage 1½°
No.4: RAF 6 4 VCL Decalage -½°
Set Back 20 per cent
Air Speed 30 M.P.H.
Aerodynamical Laboratory
U.S. Bureau of Standards
ANGLE OF WING CHORD TO WIND

Fig. 23.

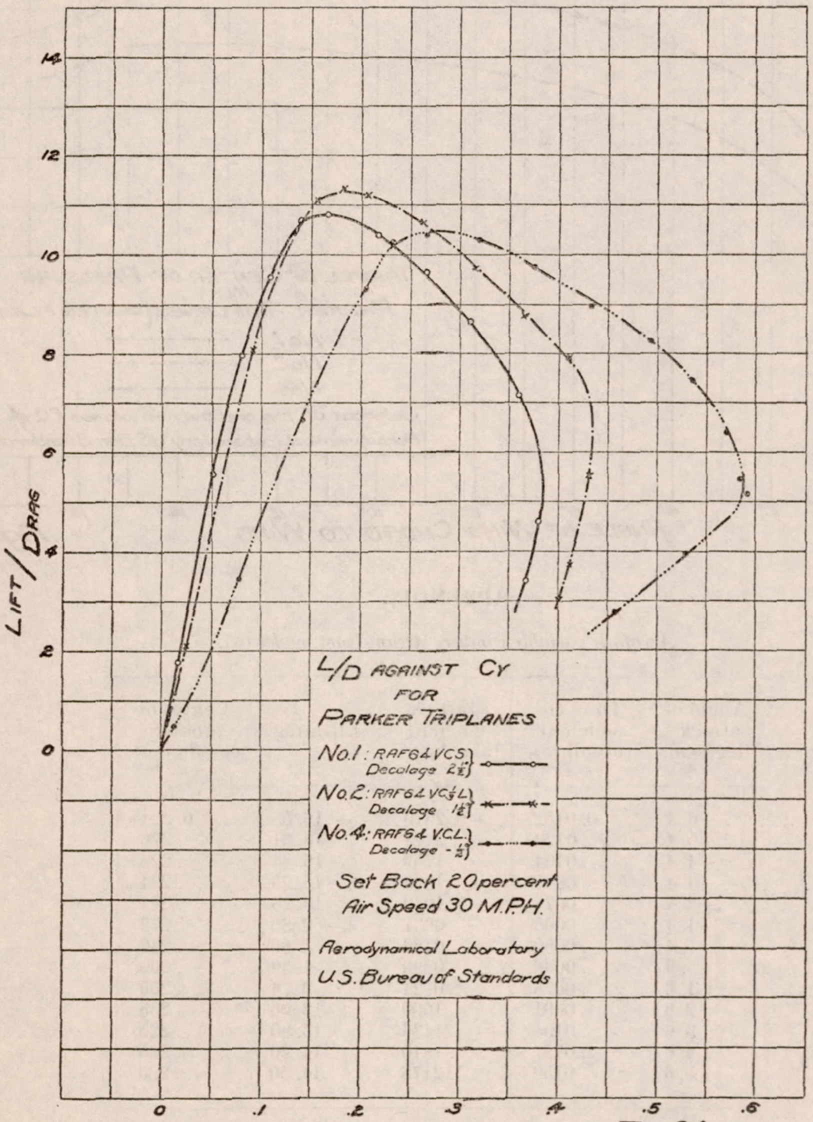

L/D AGAINST CY
FOR
PARKER TRIPLANES
No.1: RAF6∠VCS
Decalage 2½°
No.2: RAF6∠VC⅓L
Decalage 1½°
No.4: RAF6∠V.C.L.
Decalage -½°
Set Back 20 percent
Air Speed 30 M.P.H.
Aerodynamical Laboratory
U.S. Bureau of Standards
LIFT/DRAG
LIFT COEFFICIENT
0
2
4
6
8
10
12
14
.1
.2
.3
.4
.5
.6

Fig. 24.

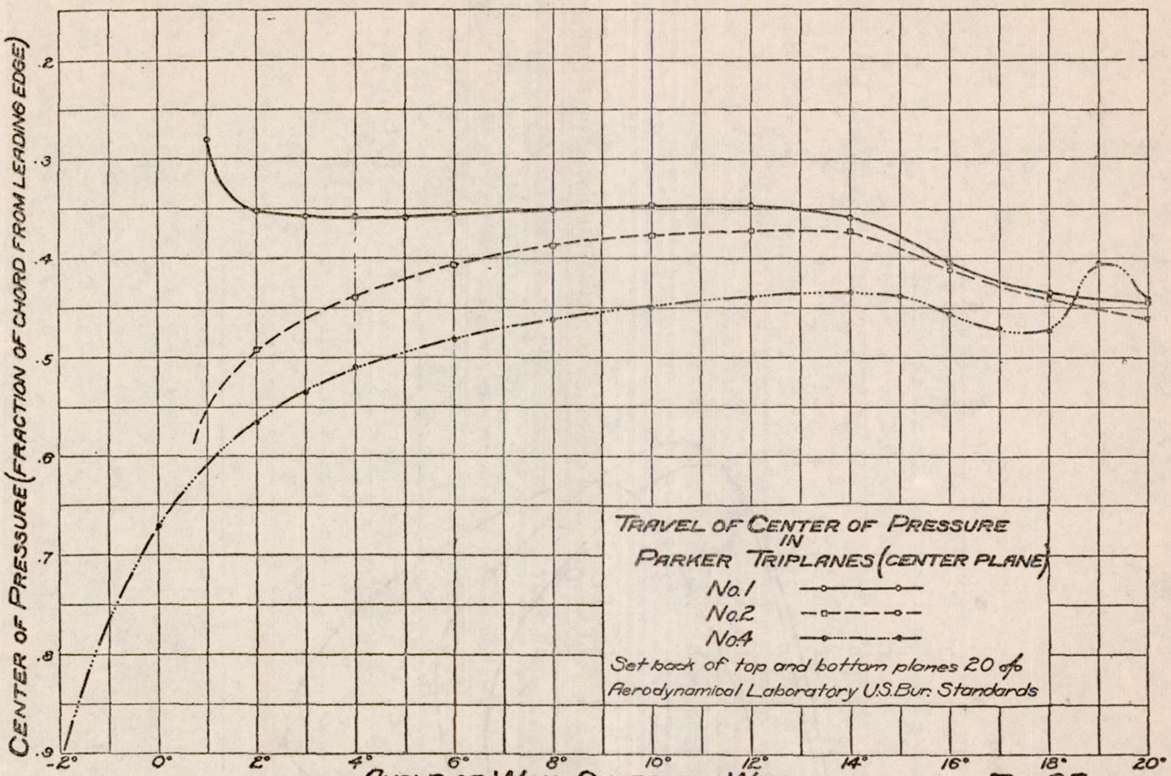


Fig. 25.

APPENDIX.

Aerofoil, variable camber, stream-line, model (a).

Angle of attack (degrees).	Drag co-efficient (absolute).	Lift co-efficient (absolute).	Lift/drag.	Center of pressure co-efficient.
−6.4	0.0152	−0.2510	−16.58	0.224
−5.4	.0129	− .2124	−16.61	.226
−4.4	.0104	− .1759	−16.84	.225
−3.4	.0088	− .1398	−15.96	.234
−2.4	.0078	− .1039	−13.23	.244
−1.4	.0065	− .0637	− 9.85	.272
− .4	.0060	− .0183	− 3.06	.242
.6	.0066	.0290	4.39	.269
1.6	.0075	.0724	9.74	.255
2.6	.0091	.1090	12.06	.238
3.6	.0104	.1436	13.80	.225
4.6	.0127	.1810	14.20	.225
5.6	.0150	.2178	14.50	.225

Model:
- Chord........ 3 inches.
- Span........ 18 inches.
- Material........ Bakelite, paper base.

Air speed........ 40 miles per hour.

Center of pressure coefficient........ Distance of center of pressure from leading edge, in fractional part of chord.

Reference line........ Angle of no lift.

(Not plotted.)

Aerofoil, variable camber, stream-line model (b).

Angle of attack (degrees).	Drag co-efficient (absolute).	Lift co-efficient (absolute).	Lift/drag.	Center of pressure co-efficient.
− 3	0. 0099	−0. 1236	−12. 48	0. 286
− 2	. 0084	− . 0886	−10. 55	. 261
− 1	. 0074	− . 0433	− 5. 85	. 269
0	. 0070	− . 0025	− . 36	. 316
1	. 0074	. 0352	4. 76	. 224
2	. 0087	. 0822	9. 45	. 252
3	. 0100	. 1183	11. 80	. 244
4	. 0114	. 1540	13. 50	. 232
6	0165	. 2230	13. 50	. 228
8	0248	. 2920	11. 80	. 225
10	. 0456	. 3420	7. 50	. 243
12	. 0760	. 3630	4. 78	. 307
14	. 0980	. 3580	3. 66	. 341
16	. 1160	. 3550	3. 06	. 356
18	. 1330	3530	2. 66	. 363
20	. 1490	. 3550	2. 38	. 366

Model:
- Chord..3 inches.
- Span..18 inches.
- Material..Bakelite, cloth base.

Air speed..30 miles per hour.
Center of pressure coefficient..Distance of center of pressure from leading edge, in fractional part of chord.
Reference line..Center line of section of aerofoil.

Aerofoil, variable camber, one-third lifting model (a).

Angle of attack (degrees).	Drag co-efficient (absolute).	Lift co-efficient (absolute).	Lift/drag.	Center of pressure coefficient.
− 4	0. 0114	−0. 0766	− 6. 74	−0. 050
− 3	. 0097	− . 0424	− 4. 37	− . 076
− 2	. 0091	− . 0002	− . 25	−4. 930
− 1	. 0087	. 0450	5. 20	. 575
0	. 0084	. 0916	10. 91	. 417
1	. 0096	. 1341	14. 00	....
2	. 0113	. 1721	15. 18	. 329
4	. 0161	. 2560	15. 26	. 294
6	. 0218	. 3182	14. 56	. 280
8	. 0303	. 3898	12. 87	. 273
10	. 0412	. 4540	11. 01	. 270
12	. 0762	. 4528	5. 94	. 307
14	. 1033	. 4266	4. 13	. 347
16	. 1255	. 4110	3. 27	. 368
18	. 1461	. 4120	2. 82	. 377
20	. 1670	. 4134	2. 47	. 383

Model:
- Chord..3 inches.
- Span..18 inches.
- Material..Bakelite, paper base.

Air speed..40 miles per hour.
Reference line..Tangent to lower surface at trailing edge.

(Not plotted.)

Aerofoil, variable camber, one-third lifting model (a)

Angle of attack (degrees).	Drag coefficient (absolute).	Lift coefficient (absolute).	Lift/drag.
−5	0.0156	−0.1103	−7.09
−4	.0126	−.0737	−5.85
−2	.0102	−.0034	−.34
−1	.0096	.0412	4.30
0	.0099	.0925	9.32
1	.0111	.1378	12.44
2	.0129	.1752	13.54
3	.0153	.2140	13.97
4	.0173	.2474	14.30
6	.0243	.3218	13.25
8	.0330	.3932	11.91
10	.0456	.4556	9.99
12	.0829	.4468	5.39
14	.1069	.4140	3.87
16	.1290	.4080	3.16
18	.1487	.4090	2.75
20	.1680	.4100	2.44

Model:
- Chord........3 inches.
- Span........18 inches.
- Material........Bakelite, paper base.

Air speed........30 miles per hour.
Reference line........Datum line of template.

Aerofoil, variable camber, one-third lifting model (b).

Angle of attack (degrees).	Drag coefficient (absolute).	Lift coefficient (absolute).	Lift/drag.
−6	0.0187	−0.1159	−6.20
−4	.0127	−.0463	−3.64
−2	.0102	.0278	2.73
0	.0107	.1246	11.67
2	.0145	.2018	13.90
3	.0165	.2366	14.35
4	.0190	.2740	14.40
6	.0268	.3510	13.08
8	.0356	.4198	11.76
10	.0481	.4810	10.00
12	.0874	.4582	5.24
14	.1094	.4290	3.92
16	.1324	.4158	3.14
18	.1509	.4122	2.73
20	.1715	.4108	2.39

Model:
- Chord........3 inches.
- Span........18 inches.
- Material........Bakelite, cloth base.

Air speed........30 miles per hour.
Reference line........Tangent to lower surface at trailing edge.
(Not plotted.)

Aerofoil, variable camber, two-thirds lifting.

Angle of attack (degrees).	Drag coefficient (absolute).	Lift coefficient (absolute).	Lift/drag.	Center of pressure coefficient.
−6	0. 0362	−0. 1243	−3. 44	+0. 174
−5	. 0295	− . 0850	−2. 88	. 061
−4	. 0248	− . 0352	−1. 42	− . 377
−3	. 0202	. 0206	1. 02	+1. 661
−2	. 0168	. 0701	4. 18	. 689
−1	. 0160	. 1177	7. 35	. 509
0	. 0157	. 1544	9. 84	. 435
1	. 0158	. 1925	12. 19	. 393
2	. 0169	. 2282	13. 52	. 366
3	. 0190	. 2684	14. 21	. 344
4	. 0220	. 3041	13. 82	. 330
6	. 0282	. 3792	13. 43	. 309
8	. 0364	. 4505	12. 38	. 297
10	. 0448	. 5110	11. 40	. 289
12	. 0571	. 5610	9. 82	. 281
14	. 0978	. 4975	5. 09	. 324
16	. 1254	. 4455	3. 56	. 360
18	. 1420	. 4270	3. 01	. 377
20	. 1619	. 4185	2. 58	. 382

Model:
- Chord .... 3 inches.
- Span .... 18 inches.
- Material .... Bakelite, cloth base.

Air speed .... 30 miles per hour.
Reference line .... Common tangent to lower surface.

Aerofoil, variable camber, lifting model (a).

Angle of attack (degrees).	Drag coefficient (absolute).	Lift coefficient (absolute).	Lift/drag.	Center of pressure coefficient.
−7	0. 0425	−0. 1114	−2. 62	0. 240
−6	. 0373	− . 0706	−1. 89	. 071
−5	. 0321	− . 0212	− . 66	− . 782
−4	. 0285	. 0288	1. 01	1. 497
−3	. 0251	. 0740	2. 95	. 790
−2	. 0236	. 1194	5. 07	. 599
−1	. 0229	. 1637	7. 16	. 511
0	. 0228	. 2028	8. 92	. 460
1	. 0232	. 2432	10. 48	. 429
2	. 0240	. 2826	11. 77	. 398
3	. 0262	. 3200	12. 20	. 381
4	. 0284	. 3588	12. 62	. 367
6	. 0349	. 4324	12. 40	. 345
8	. 0430	. 5100	11. 88	. 331
10	. 0528	. 5780	10. 95	. 324
12	. 0636	. 6415	10. 10	. 317
14	. 0768	. 6965	9. 07	. 314
16	. 0901	. 7325	8. 13	. 311
17	. 1363	. 4985	3. 66	....
18	. 1467	. 4765	3. 25	. 386
20	. 1665	. 4650	2. 79	. 392

Model:
- Chord .... 3 inches.
- Span .... 18 inches.
- Material .... Bakelite, cloth base.

Air speed .... 30 miles per hour.
Reference line .... Common tangent to lower surface.
(Not plotted.)

Aerofoil, variable camber, lifting model (b).

Angle of attack (degrees).	Drag coefficient (absolute).	Lift coefficient (absolute).	Lift/drag.
−8	0. 0511	−0. 1275	−2. 49
−6	. 0400	− . 0729	−1. 82
−4	. 0305	. 0300	. 98
−2	. 0251	. 1263	5. 04
0	. 0225	. 2135	9. 48
2	. 0228	. 2930	12. 84
3	. 0251	. 3330	13. 25
4	. 0275	. 3738	13. 59
6	. 0341	. 4525	13. 28
8	. 0421	. 5265	12. 50
10	. 0514	. 5945	11. 57
12	. 0645	. 6690	10. 37
14	. 0770	. 7190	9. 34
16	. 0927	. 7610	8. 21
17	. 1371	. 5190	3. 78
18	. 1486	. 5000	3. 36

Model:
- Chord .... 3 inches.
- Span .... 18 inches.
- Material .... Bakelite, cloth base.

Air speed .... 30 miles per hour.
Reference line .... Common tangent to lower surface.

Aerofoil R. A. F. 6.

Angle of attack (degrees).	Drag coefficient (absolute).	Lift coefficient (absolute).	Lift/drag.
−4	0. 0266	−0. 0865	−3. 25
−3	. 0220	− . 0455	−2. 07
−2	. 0181	− . 0016	− . 87
−1	. 0159	. 0407	2. 56
0	. 0148	. 0900	6. 10
1	. 0138	. 1453	10. 51
2	. 0141	. 1927	13. 66
3	. 0158	. 2316	14. 67
4	. 0178	. 2656	14. 91
6	. 0241	. 3316	13. 73
8	. 0326	. 4042	12. 41
10	. 0421	. 4650	11. 05
12	. 0534	. 5220	9. 78
14	. 0848	. 4910	5. 79
16	. 1080	. 4360	4. 04
18	. 1297	. 4242	3. 27
20	. 1457	. 4274	2. 94
22	. 1656	. 4258	2. 57
24	. 1886	. 4232	2. 24

Model:
- Chord .... 3 inches.
- Span .... 18 inches.
- Material .... Wood.

Air speed .... 30 miles per hour.
Reference line .... Common tangent to lower surface.
(Not plotted.)

Parker biplane No. 1.

Angle of attack (degrees).	Drag coefficient (absolute).	Lift coefficient (absolute).	Lift/drag.	Center of pressure coefficient.
−2	0.0146	−0.0587	−4.02	0.325
−1	.0132	− .0253	−1.92	.392
0	.0118	.0122	1.03	.165
1	.0109	.0490	4.50	.290
2	.0107	.0837	7.82	.309
3	.0116	.1174	10.12	.320
4	.0125	.1485	11.89	.329
5	.0149	.1788	12.00	.327
6	.0170	.2056	12.09	.328
8	.0226	.2596	11.50	.329
10	.0305	.3130	10.27	.337
12	.0395	.3615	9.14	.341
14	.0546	.3965	7.26	.346
16	.0840	.3875	4.61	.396
18	.1100	.3710	3.37	.399
20	.1272	.3615	2.84	.405

Upper plane.......................V. C. S.
Lower plane.......................R. A. F. 6.
Chord.......................3 inches.
Span.......................18 inches.
Gap.......................3 inches.
Stagger.......................20 per cent negative.
Decalage.......................Upper plane set at 2½° less incidence than lower.
Air speed.......................30 miles per hour.
Reference line.......................Chord of R. A. F. 6, lower plane.
Center of pressure.......................At chord of lower plane.

Parker biplane No. 2.

Angle of attack (degrees).	Drag coefficient (absolute).	Lift coefficient (absolute).	Lift/drag.	Center of pressure coefficient.
−2	0.0158	−0.0334	−2.12	0.052
−1	.0136	− .0010	− .07	−6.300
0	.0126	.0344	2.73	.536
1	.0115	.0705	6.13	.435
2	.0109	.1051	9.65	.412
3	.0115	.1423	12.37	.403
4	.0125	.1720	13.78	.393
6	.0179	.2295	12.82	.378
8	.0234	.2800	12.00	.375
10	.0304	.3380	11.11	.381
12	.0395	.3810	9.65	.385
14	.0556	.4200	7.55	.405
16	.0855	.4080	4.77	.428
18	.1061	.3860	3.64	.427
20	.1259	.3670	2.92	.424

Upper plane.......................V. C. one-third lifting.
Lower plane.......................R. A. F. 6.
Chord.......................3 inches.
Span.......................18 inches.
Gap.......................3 inches.
Stagger.......................20 per cent negative.
Decalage.......................Upper plane set at 1½° less incidence than lower.
Air speed.......................30 miles per hour.
Reference line.......................Chord of lower plane R. A. F. 6.
Center of pressure.......................At chord of lower plane.

Parker biplane No. 3.

Angle of attack (degrees).	Drag coefficient (absolute).	Lift coefficient (absolute).	Lift/drag.	Center of pressure coefficient.
−4	0.0251	−0.0495	−1.97	+0.107
−3	.0212	− .0090	− .42	−1.276
−2	.0186	.0312	1.68	+ .990
−1	.0169	.0686	4.05	.653
0	.0165	.1075	6.52	.555
1	.0158	.1427	9.06	.512
2	.0160	.1764	11.01	.481
3	.0173	.2073	12.01	.463
4	.0194	.2380	12.29	.452
6	.0248	.2944	11.85	.437
8	.0321	.3530	10.99	.432
10	.0415	.4090	9.86	.430
12	.0520	.4615	8.88	.433
14	.0709	.4845	6.84	.458
16	.1005	.4485	4.46	.460
18	.1226	.4230	3.45	.457
20	.1412	.4025	2.85	.453

Upper plane.......... V. C. two-thirds lifting.
Lower plane.......... R. A. F. 6.
Chord.......... 3 inches.
Span.......... 18 inches.
Gap.......... 3 inches.
Stagger.......... 20 per cent negative.
Decalage.......... Upper plane set at ½° less incidence than lower.
Air speed.......... 30 miles per hour.
Reference line.......... Chord of lower plane, R. A. F. 6.
Center of pressure.......... At chord of lower plane.

Parker biplane No. 4.

Angle of attack (degrees).	Drag coefficient (absolute).	Lift coefficient (absolute).	Lift/drag.	Center of pressure coefficient.
−5	0.0331	−0.0652	−1.97	0.159
−4	.0284	− .0275	− .97	− .360
−3	.0247	.0116	.47	2.824
−2	.0221	.0472	2.14	.952
−1	.0205	.0820	4.00	.712
0	.0198	.1163	5.87	.614
1	.0197	.1531	7.76	.567
2	.0200	.1903	9.52	.534
3	.0206	.2234	10.84	.511
4	.0224	.2536	11.35	.498
6	.0278	.3136	11.27	.481
8	.0350	.3720	10.63	.472
10	.0440	.4275	9.73	.464
12	.0547	.4820	8.81	.463
14	.0722	.5180	7.19	.489
15	.0823	.5205	6.32	.517
16	.0898	.5275	5.87	.534
18	.1051	.5395	5.14	.557
20	.1391	.4255	3.06	.498
22	.1578	.4120	2.61	.491

Upper plane.......... V. C. L.
Lower plane.......... R. A. F. 6.
Chord.......... 3 inches.
Span.......... 18 inches.
Gap.......... 3 inches.
Stagger.......... 20 per cent negative.
Decalage.......... Upper plane set at ½° greater incidence than lower.
Air speed.......... 30 miles per hour.
Reference line.......... Chord of lower plane, R. A. F. 6.
Center of pressure.......... At chord of lower plane.

Parker biplane No. 5.

Angle of attack (degrees).	Drag coefficient (absolute).	Lift coefficient (absolute).	Lift/drag.	Center of pressure coefficient.
−2	0. 0124	−0. 0601	−4. 85	0. 164
−1	. 0109	− . 0274	−2. 50	. 231
0	. 0094	. 0097	1. 04	− . 039
1	. 0089	. 0478	5. 36	. 127
2	. 0089	. 0840	9. 41	. 153
3	. 0101	. 1133	11. 27	. 145
4	. 0118	. 1442	12. 21	. 144
5	. 0138	. 1735	12. 60	. 150
6	. 0163	. 2014	12. 33	. 151
8	. 0223	. 2580	11. 58	. 158
10	. 0294	. 3080	10. 48	. 164
12	. 0388	. 3580	9. 23	. 175
14	. 0564	. 4110	7. 29	. 189
16	. 0886	. 3900	4. 40	. 214
18	. 1127	. 3870	3. 44	. 233
20	. 1328	. 3860	2. 91	. 250

Upper plane........R. A. F. 6.
Lower plane........V. C. S.
Chord........3 inches.
Span........18 inches.
Gap........3 inches.
Stagger........20 per cent positive.
Decalage........Lower plane set at 2½° less incidence than upper.
Air speed........30 miles per hour.
Reference line........Chord of R. A. F. 6.
Center of pressure........At chord of lower plane.

Parker biplane No. 6.

Angle of attack (degrees).	Drag coefficient (absolute).	Lift coefficient (absolute).	Lift/drag.	Center of pressure coefficient.
−3	0. 0161	−0. 0497	−3. 10	−0. 021
−2	. 0138	− . 0198	−1. 44	− . 207
−1	. 0124	. 0107	. 86	. 725
0	. 0108	. 0481	4. 45	. 275
1	. 0106	. 0841	7. 96	. 219
2	. 0107	. 1153	11. 10	. 206
3	. 0121	. 1530	12. 67	. 198
4	. 0140	. 1845	13. 22	. 192
5	. 0160	. 2130	13. 34	. 184
6	. 0195	. 2420	12. 41	. 179
8	. 0264	. 2964	11. 24	. 176
10	. 0340	. 3510	10. 33	. 179
12	. 0437	. 3955	9. 05	. 180
14	. 0558	. 4355	7. 81	. 182
16	. 0887	. 4230	4. 77	. 194
18	. 1150	. 4105	3. 57	. 223
20	. 1333	. 3980	2. 99	. 242

Upper plane........R. A. F. 6.
Lower plane........V. C. one-third lifting.
Chord........3 inches.
Span........18 inches.
Gap........3 inches.
Stagger........20 per cent positive.
Decalage........Lower plane set at 1½° less incidence than upper.
Air speed........30 miles per hour.
Reference line........Chord of R. A. F. 6.
Center of pressure........At chord of lower plane.

Parker biplane No. 7.

Angle of attack (degrees).	Drag coefficient (absolute).	Lift coefficient (absolute).	Lift/drag.	Center of pressure coefficient.
−4	0. 0242	−0. 0391	−1. 61	−0. 277
−3	. 0207	− . 0035	− . 17	−4. 070
−2	. 0182	. 0310	1. 70	. 757
−1	. 0160	. 0662	4. 13	. 437
0	. 0149	. 1022	6. 85	. 333
1	. 0141	. 1385	9. 81	. 283
2	. 0147	. 1711	11. 61	. 260
3	. 0164	. 2041	12. 41	. 241
4	. 0185	. 2330	12. 55	. 226
6	. 0241	. 2912	12. 11	. 211
8	. 0314	. 3464	11. 03	. 211
10	. 0393	. 4005	10. 19	. 217
12	. 0498	. 4520	9. 08	. 218
14	. 0620	. 4980	8. 04	. 224
15	. 0726	. 5160	7. 11	. 224
16	. 0872	. 4910	5. 63	. 222
18	. 1142	. 4610	4. 04	. 239
20	. 1455	. 4400	3. 04	. 256

Upper plane..R. A. F. 6.
Lower plane..V. C. two-thirds lifting.
Chord..3 inches.
Span...18 inches.
Gap..3 inches.
Stagger..20 per cent positive.
Decalage...Lower plane set at ½° less incidence than upper.
Air speed..30 miles per hour.
Reference line.....................................Chord of R. A. F. 6.
Center of pressure.................................At chord of lower plane.

Parker biplane No. 8.

Angle of attack (degrees).	Drag coefficient (absolute).	Lift coefficient (absolute).	Lift/drag.	Center of pressure coefficient.
−5	0. 0293	−0. 0385	−1. 32	−0. 407
−4	. 0258	− . 0046	− . 18	−3. 820
−3	. 0231	. 0305	1. 32	1. 070
−2	. 0210	. 0640	3. 04	. 579
−1	. 0193	. 0983	5. 10	. 425
0	. 0186	. 1347	7. 23	. 350
1	. 0189	. 1730	9. 14	. 309
2	. 0193	. 2063	10. 70	. 285
3	. 0209	. 2409	11. 54	. 265
4	. 0233	. 2701	11. 60	. 250
6	. 0290	. 3290	11. 33	. 237
8	. 0371	. 3880	10. 46	. 230
10	. 0458	. 4410	9. 64	. 231
12	. 0562	. 4930	8. 80	. 233
14	. 0684	. 5420	7. 94	. 237
15	. 0747	. 5660	7. 57	. 242
16	. 0914	. 5510	6. 03	. 240
18	. 1100	. 5390	4. 91	. 239
20	. 1280	. 5450	4. 26	. 238
22	. 1880	. 4780	2. 83	. 276
24	. 1915	. 4500	2. 35	. 280

Upper plane..R. A. F. 6.
Lower plane..V. C. L.
Chord..3 inches.
Span...18 inches.
Gap..3 inches.
Stagger..20 per cent positive.
Decalage...Lower plane set at ½° greater incidence than upper.
Air speed..30 miles per hour.
Reference line.....................................Chord of R. A. F. 6.
Center of pressure.................................At chord of lower plane.

Parker triplane No. 1.

Angle of attack (degrees).	Drag coefficient (absolute).	Lift coefficient (absolute).	Lift/drag.	Center of pressure coefficient.
0	0. 0099	−0. 0163	−1. 64	0. 469
1	. 0091	. 0162	1. 78	. 281
2	. 0090	. 0506	5. 59	. 352
3	. 0100	. 0796	7. 97	. 358
4	. 0113	. 1080	9. 58	. 359
5	. 0129	. 1392	10. 70	. 361
6	. 0154	. 1660	10. 78	. 356
8	. 0209	. 2172	10. 38	. 351
10	. 0275	. 2656	9. 67	. 347
12	. 0361	. 3115	8. 64	. 348
14	. 0504	. 3600	7. 14	. 360
16	. 0824	. 3785	4. 60	. 405
18	. 1082	. 3675	3. 39	. 435
20	. 1265	. 3630	2. 87	. 445

Top plane..V. C. S.
Middle plane..R. A. F. 6.
Bottom plane..V. C. S.
Chord..3 inches.
Span..18 inches.
Gap..3 inches.
Stagger..Top and bottom planes set 20 per cent of chord behind middle plane.
Decalage..Top and bottom planes set at 2½° less incidence than middle plane.
Air speed..30 miles per hour.
Reference line..Chord of R. A. F. 6.
Center of pressure..At chord of middle plane.

Parker triplane No. 2.

Angle of attack (degrees).	Drag coefficient (absolute).	Lift coefficient (absolute).	Lift/drag.	Center of pressure coefficient.
−2	0. 0146	−0. 0353	−2. 42	−0. 049
0	. 0118	. 0243	2. 05	. 870
2	. 0110	. 0885	8. 09	. 491
4	. 0140	. 1553	11. 10	. 438
5	. 0161	. 1829	11. 34	. 422
6	. 0186	. 2076	11. 19	. 406
8	. 0246	. 2620	10. 63	. 387
10	. 0325	. 3160	9. 72	. 378
12	. 0413	. 3656	8. 86	. 372
14	. 0518	. 4102	7. 92	. 373
16	. 0778	. 4290	5. 52	. 411
18	. 1108	. 4128	3. 73	. 440
20	. 1323	. 4010	3. 03	. 461

Top plane..V. C. one-third lifting.
Middle plane..R. A. F. 6.
Bottom plane..V. C. one-third lifting.
Chord..3 inches.
Span..18 inches.
Gap..3 inches.
Stagger..Top and bottom planes set 20 per cent of chord behind middle plane.
Decalage..Top and bottom planes set at 1½° less incidence than middle plane.
Air speed..30 miles per hour.
Reference line..Chord of R. A. F. 6.
Center of pressure..At chord of middle plane.

Parker triplane No. 4.

Angle of attack (degrees).	Drag coefficient (absolute).	Lift coefficient (absolute).	Lift/drag.	Center of pressure coefficient.
−5	0.0310	−0.0218	−0.70	−1.191
−4	.0275	.0129	.47	4.208
−2	.0227	.0779	3.43	.927
0	.0212	.1414	6.68	.670
2	.0220	.2048	9.32	.566
3	.0228	.2324	10.27	.536
4	.0255	.2652	10.39	.510
6	.0312	.3205	10.30	.482
8	.0385	.3755	9.77	.462
10	.0483	.4330	8.96	.450
12	.0587	.4855	8.26	.440
14	.0716	.5345	7.47	.434
15	.0781	.5540	7.10	.437
16	.0893	.5695	6.38	.456
17	.0988	.5755	5.82	.470
18	.1064	.5825	5.48	.473
19	.1142	.5910	5.17	.404
20	.1332	.5275	3.96	.441
22	.1640	.4565	2.78	.478
24	.1870	.4465	2.39	.487

Top plane....V. C. L.
Middle plane....R. A. F. 6.
Bottom plane....V. C. L.
Chord....3 inches.
Span....18 inches.
Gap....3 inches.
Stagger....Top and bottom planes set 20 per cent of chord behind middle plane.
Decalage....Top and bottom planes set at ½° greater incidence than middle plane.
Air speed....30 miles per hour.
Reference line....Chord of R. A. F. 6.
Center of pressure....At chord of middle plane.

Lift/drag against speed.

Parker biplane back stagger.		Parker biplane forward stagger.		R. A. F. 6 biplane.		Parker triplane.		R. A. F. 6 triplane.	
Speed.	Lift/drag.	Speed.	Lift/drag.	Speed.	Lift/drag.	Speed.	Lift/drag.	Speed.	Lift/drag.
3.32	5.55	3.440	7.05	3.58	2.30	3.42	7.30	3.58	2.10
2.54	9.75	2.600	12.38	2.42	5.22	2.73	10.10	2.42	5.05
2.25	12.33	2.240	14.24	1.90	9.20	2.34	11.80	1.90	8.80
1.95	15.13	1.920	15.40	1.65	12.00	1.95	13.15	1.65	11.25
1.77	16.51	1.750	15.60	1.50	13.20	1.80	13.10	1.50	12.40
1.35	13.00	1.630	15.40	1.40	13.90	1.69	12.60	1.50	12.90
1.24	11.80	1.390	13.20	1.26	12.80	1.25	10.28	1.26	11.70
1.15	10.40	1.280	11.84	1.14	10.90	1.17	9.35	1.14	10.70
1.06	8.50	1.190	10.80	1.06	10.35	1.10	8.60	1.06	9.90
1.02	7.40	1.070	9.13	1.00	9.70	1.05	7.70	1.00	9.10
1.00	5.24	1.025	8.18	....	....	1.02	6.55	....	....
....	....	1.000	7.80	....	....	1.00	5.26	....	....

Deflection of rib under overloads.

Load.		Deflection.					
		In inches, at distance from leading edge of—					
Number of flying loads.	Total load (pounds).	$1\frac{1}{2}$ inches (front spar).	12 inches (A).	21 inches (B).	30 inches (C).	39 inches (rear spar).	60 inches (trailing edge) (D).
1	33.5	0	0	0	0	0	0
2	67.0	0	.066	.081	.061	0	−.020
3	100.5	0	.092	.130	.111	0	−.050
4	134.0	0	.137	.178	.164	0	−.103
5	167.5	0	.186	.228	.199	0	−.105
6	201.0	0	.208	.260	.229	0	−.089
7	234.5	0	.244	.303	.266	0	−.095
8	268.0	0	.324	.349	.306	0	−.090
9	301.5	0	.354	.385	.342	0	−.093
10	335.0	0	.400	.437	.393	0	−.092
11	368.5	Rib failed by buckling of channel flanges.					

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