NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 468

THE INTERFERENCE BETWEEN STRUTS IN VARIOUS COMBINATIONS

By DAVID BIERMANN and WILLIAM H. HERRNSTEIN, JR.

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AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	s	second (or hour)	sec. (or hr.)
Force	F	weight of 1 kilogram	kg	weight of 1 pound	lb.
Power	P	kg/m/s		horsepower	hp.
Speed		{km/h	k.p.h.	mi./hr.	m.p.h
		{m/s	m.p.s.	ft./sec.	f.p.s.

2. GENERAL SYMBOLS, ETC.

W, Weight $=mg$

g, Standard acceleration of gravity $=9.80665$ m/s$^2=32.1740$ ft./sec.^{2}

m, Mass $=\frac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} s^2) at 15° C. and 760 mm $=0.002378$ (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m$^3=0.07651$ lb./ft.^{3}.

mk^2, Moment of inertia (indicate axis of the radius of gyration k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord.

$\frac{b^2}{S}$, Aspect ratio.

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed

q, Dynamic (or impact) pressure $=\frac{1}{2}\rho V^2$.

L, Lift, absolute coefficient $C_L=\frac{L}{qS}$

D, Drag, absolute coefficient $C_D=\frac{D}{qS}$

D_o, Profile drag, absolute coefficient $C_{Do}=\frac{D_o}{qS}$

D_i, Induced drag, absolute coefficient $C_{D_i}=\frac{D_i}{qS}$

D_p, Parasite drag, absolute coefficient $C_{D_p}=\frac{D_p}{qS}$

C, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

R, Resultant force.

i_w, Angle of setting of wings (relative to thrust line).

i_t, Angle of stabilizer setting (relative to thrust line).

Q, Resultant moment.

Ω, Resultant angular velocity.

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, at 15° C., the corresponding number is 234,000;

or for a model of 10 cm chord 40 m/s, the corresponding number is 274,000.

C_p, Center of pressure coefficient (ratio of distance of c. p. from leading edge to chord length).

α, Angle of attack.

ϵ, Angle of downwash.

α_o, Angle of attack, infinite aspect ratio.

α_i, Angle of attack, induced.

α_o, Angle of attack, absolute. (Measured from zero lift position.)

γ Flight path angle.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

NAVY BUILDING, WASHINGTON, D.C.

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REPORT No. 468

THE INTERFERENCE BETWEEN STRUTS IN VARIOUS COMBINATIONS

By David Biermann and William H. Herrnstein, Jr.

SUMMARY

This report presents the results of tests made in the N.A.C.A. 7- by 10-foot wind tunnel to determine the interference drag arising from various arrangements of streamline struts and round struts, or cylinders. Determinations were made of the interference drag of struts spaced side by side, struts in tandem, tandem struts encased in a single fairing, a strut intersecting a plane, and struts intersecting to form a V. *Three sizes of struts were used for most of the tests.*

These tests show that the interference drag arising from struts in close proximity may be of considerable magnitude, in some instances amounting to more than the drag of the struts themselves.

INTRODUCTION

With the increasing demand for higher speeds in flight, attention has been focused on all possible methods of reducing the drag of aircraft. Considerable coordinated information has been compiled on the drag of component parts of airplanes, but relatively little is known about the interference resulting from combining these parts into an airplane. Until recently not much systematic work has been done on the general subject of interference.

The investigation reported in this paper has been confined to the determination of interference drag arising from various combinations of struts, both streamline and round. Struts were tested, side by side, in tandem, and intersecting at various angles to form V's. Tests were made on a streamline strut intersecting plane surfaces of various chords. The drag of tandem struts encased in a single fairing was determined for two types of fairings. Incidental tests were made to determine the drag of struts of various sizes and fineness ratios. Three sizes of struts were used throughout the program, with some exceptions, to determine if possible to what extent the rules of dynamic similarity may be applied to interference tests in wind tunnels.

Many of the tests herein reported have direct applications in airplane design. Although there has been an attempt to cover the subject of strut interference in a systematic fashion, the limitations of time and equipment have necessitated curtailing the program. Further tests on interference between struts and wheels are being made in connection with a study of landing gears, and will be reported at a later date.

APPARATUS AND METHODS

The N.A.C.A. 7- by 10-foot wind tunnel in which these tests were made is completely described with its equipment in reference 1. The standard force-test model support was used throughout these tests.

The streamline strut models were made from Navy no. 1 strut-section offsets given in table I. With a few exceptions to be discussed later, the tests were made on struts of three section sizes: 1 by 3 inches, 1.75 by 5.25 inches, and 2.5 by 7.5 inches. The models were made of white pine, sanded smooth and shellacked. The surface was not highly polished, but was sufficiently smooth to be comparable with good commercial practice. All model dimensions were held to ± 0.010 inch. The round struts (cylinders) were made from seamless steel tubing, accurate to ± 0.004 inch. The surface was finished bright but not highly polished. The diameters of tubing used were 1, 1.75, and 2.5 inches.

STRUT ARRANGEMENTS

Struts alone, streamline and round.—Preliminary to the interference tests each different size of strut was tested for drag. An 8-foot length of strut was mounted horizontally at its center on the force-test support. At each tip independently supported struts were mounted and extended through the tunnel jet boundary, in an attempt to simulate infinite-length conditions. A gap of one thirty-second inch was left between the active strut and each dummy extension.

Side-by-side struts, streamline and round.—In order to determine the interference drag arising from two parallel struts located side by side, a 12-foot length of strut was mounted independently above the active strut previously described. (See fig. 1.) Drag was measured only on the active lower strut, the assumption being that the drag of the two struts was equal. The spacing between the struts was varied by moving the fixed 12-foot length of strut away from the active strut in small increments until the effects were no longer noticeable.

Struts in tandem, streamline and round.—The set-up to measure interference drag of tandem struts was identical to the one used for side-to-side spacings except that the fixed strut was located first at different spacings to the rear of the active strut and then located at different spacings in front of the active strut. The tunnel balance thus measured the drag of a strut plus the interference effect of a strut behind it or in front of it, as the case might be. By simple addition the interference effect of either strut on the other as well as the total interference, may be computed.

Tandem struts faired together, streamline and round.—Tandem streamline struts are sometimes faired together by the simple procedure of wrapping fabric around the pair and doping it. In order to simulate this condition a special model was built. A 1.75- by 5.25-inch strut was sawed lengthwise along the plane of maximum thickness. The leading-edge portion was separated from the trailing-edge portion by a distance of 20 inches and this intervening space was filled up with five 4- by 1.75-inch boards. This unit was bolted together, forming a flat-sided section 1.75 inches thick with a 25.25-inch chord and an 8-foot span. Two dummy tip extensions of the same section were also made. This model, representing streamline struts faired together with a flat-sided section, was mounted in the tunnel in the same manner as were the struts alone in previous tests. The spacing of these hypothetical struts was reduced in increments of 4 inches by successive removal of the intervening boards. Only one strut size was used for these tests.

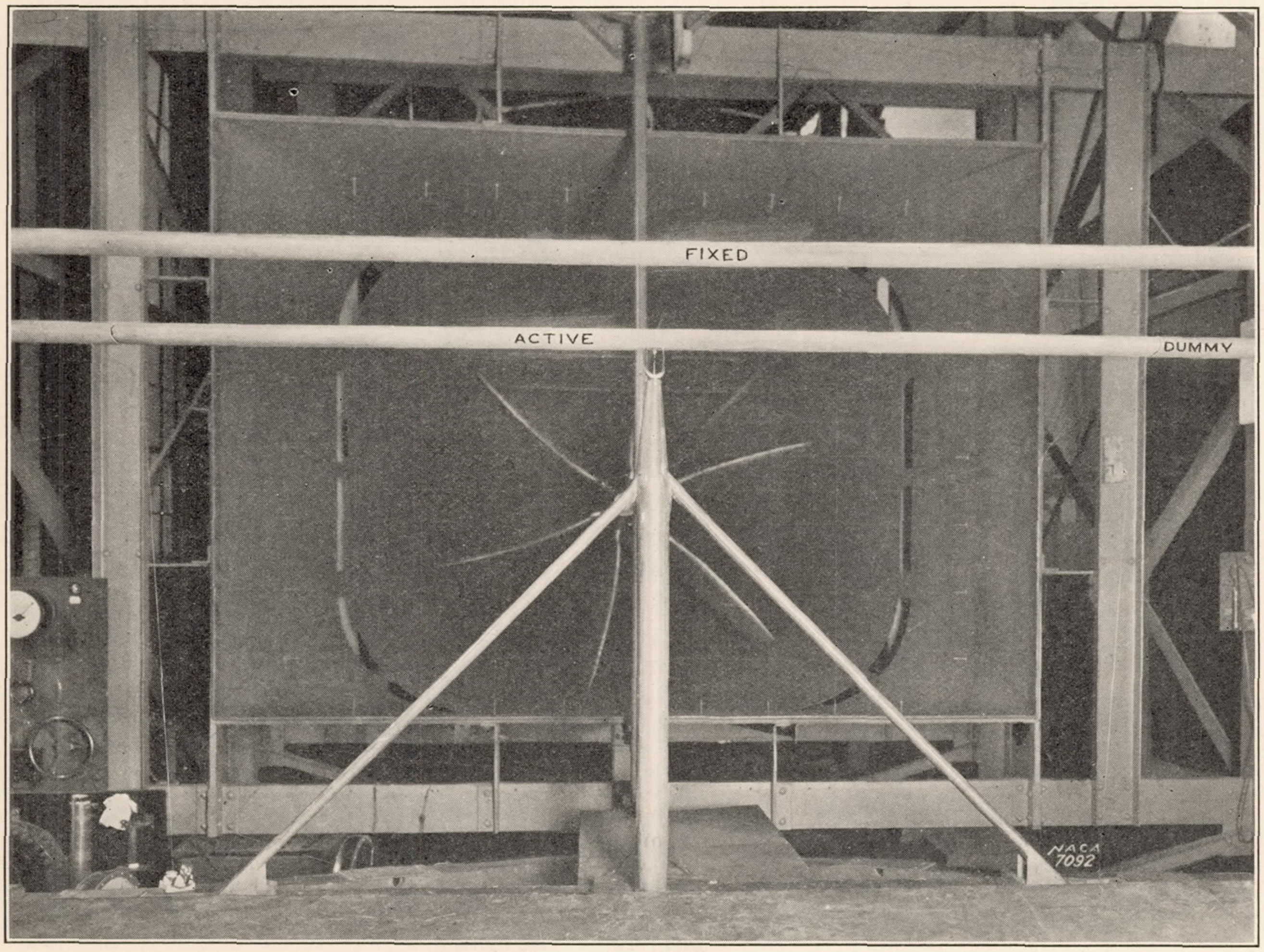


FIGURE 1.—Streamline struts spaced side by side, showing method of support and dummy tip extensions.

Obviously the best and most practicable method of fairing tandem cylinders that are relatively close together is to encase them in a single streamline fairing. In order to accomplish this it is necessary to decide on the fairing form to use; the form for minimum drag will vary, of course, with the ratio of cylinder diameter to spacing. Since the Navy no. 1 strut section has both good aerodynamic and good geometric properties for housing tandem struts, it was selected as a basic section for housing tandem cylinders. The fairing dimensions to give the least drag for any cylinder size and spacing may be calculated from tests on struts of various fineness ratios. Tests were made on Navy no. 1 struts of four fineness ratios: 3, 4, 6.25, and 8.34. The variation was made in thickness only, the chord being held constant at 7.5 inches. These struts, 8 feet long, were mounted in the tunnel in the same manner as in previous tests.

A strut intersecting a plane.—Tests were made to determine the interference drag arising from a 2.25- by 6.75-inch strut, 23 inches long, intersecting the surface of the flat-sided section previously used for fairing tandem struts. The strut was mounted at the center of the plane with a hinge-type fitting in such a manner that the angle between the strut and the plane, measured in a plane perpendicular to the tunnel axis, could be varied through the range from 20° to 90°. This test was made with planes of three chord sizes: 25.25 inches, 17.25 inches, and 9.25 inches. Several sizes of fillets were also used at the intersection of strut and plane.

Intersecting struts.—Struts intersecting to form a V in which the included angle could be varied from 15° to 180° were mounted in the tunnel on the regular force-test support. One leg of the V was supported at its midpoint, the other leg being allowed to swing in a plane perpendicular to the tunnel axis. Each strut was 32 inches long. No dummy tip extensions were considered necessary for this set-up, inasmuch as the interference did not extend to the tips to an appreciable extent. Several sizes of fillets were used for a number of angular settings of the struts.

General considerations.—Although most of the results were obtained at an air speed of 80 miles per hour, many of the tests were run at several lower speeds also. These additional test points were taken in order to increase the accuracy of the single test point by determining a curve, and also to show whether the drag coefficient changed with air speed for any given set-up. The tare drag was measured for all struts alone by suspending them independent of the balance support, providing only a small clearance. The forces on streamline struts alone were measured to within ±0.03 pound; but for cylinders and for models in which unsteady flow conditions prevailed to an appreciable extent they were measured to ±0.1 pound.

RESULTS AND DISCUSSION

The observed data and computed nondimensional coefficients of drag and interference drag are presented in tables II and III and in figures 2 to 14, inclusive. The terms and coefficients used are defined as follows:

Drag coefficient,

$$C_D = \frac{\text{drag}}{q\,d\,l}$$

Interference drag = drag of the bodies in combination − the sum of the drags of the bodies tested separately

Interference-drag coefficient,

$$C_{D_{int}} = \frac{\text{interference drag}}{q\,d\,l}$$

Length of strut equivalent to interference drag

$$= \frac{\text{interference drag}}{\text{drag per unit length of strut}}$$

where q, dynamic pressure in pounds per square foot.
d, diameter or maximum cross-wind dimension of strut in feet.
l, length of strut in feet.

NOTE.—Interference-drag coefficients are based on d and l of one strut only.

The drag coefficients are corrected for tare drag and for static-pressure variation in the tunnel by the usual methods.

STRUTS ALONE

Streamline struts.—The results for streamline struts tested alone are given in figures 2 and 3. Figure 2 shows the variation of C_D with Reynolds Number for the three sizes of struts tested, all of fineness ratio 3.

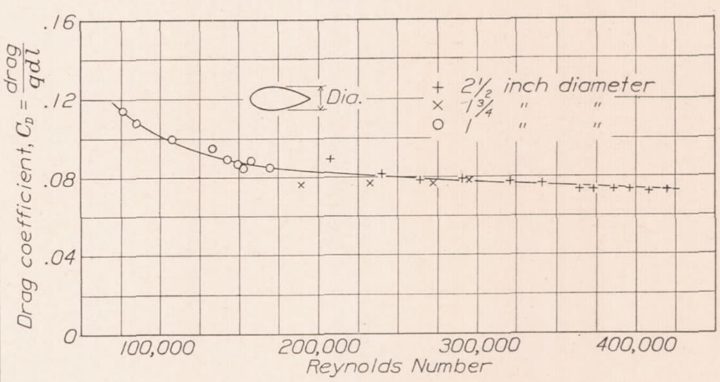


FIGURE 2.—Variation of drag of streamline struts with Reynolds Number. Navy no. 1 strut section, fineness ratio, 3.

The drag coefficients are consistently higher than those obtained from an early test (reference 2), but later tests (reference 4) agree more closely with the present results and indicate that the results of reference 2 were influenced by the presence of a support strut.

Figure 3, which is only incidental to the present report, shows the relation between C_D and fineness ratio for Navy no. 1 struts. These results, too, differ somewhat from those of previous tests in that minimum drag occurs at a fineness ratio of about 5 instead of at 3 or 4 as observed for other tests. Furthermore, the

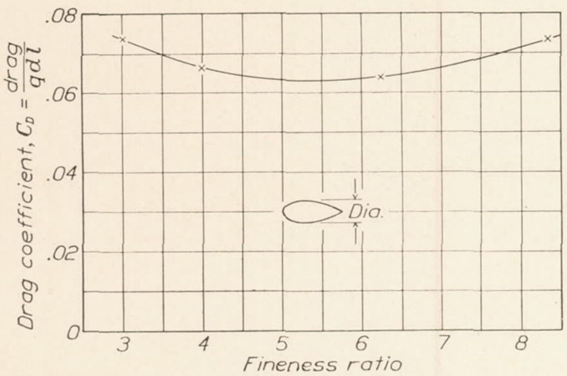


FIGURE 3.—Drag of Navy no. 1 struts of various fineness ratios. Air speed, 80 m.p.h. Reynolds Number, 420,000.

drag coefficient does not change as greatly with small changes of fineness ratio as the other tests show it to have done. Results from recent N.A.C.A. tests on symmetrical airfoils (reference 5) agree, however, fairly well with these results, in that the drag coefficient does not change rapidly with changes in fineness ratio within the range from 3 to 7. In view of the differences between these results and those of former tests, it is suggested that further investigation be made of the subject.

Round struts (cylinders) alone.—The variation of C_D with Reynolds Number for three sizes of cylinders is given in figure 4. In general, these results check previous tests of cylinders fairly well. It is noted that each size of cylinder defines a slightly different C_D for a

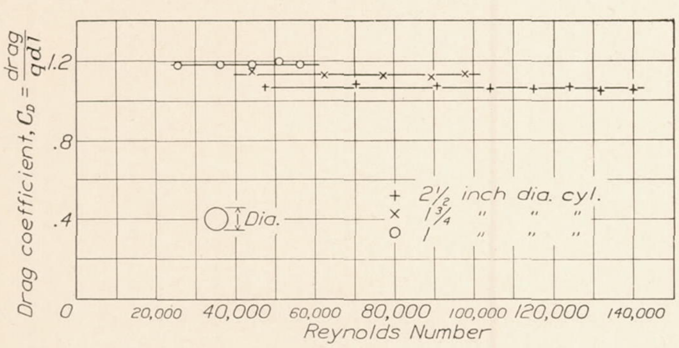


FIGURE 4.—Variation of drag of cylinders with Reynolds Number.

given Reynolds Number. The reason for this is not readily apparent, inasmuch as several factors pertinent to wind tunnels might possibly account for the effect. More detailed work on this subject would probably disclose information concerning this effect.

STRUTS SIDE BY SIDE

Streamline struts.—Streamline struts spaced side by side 6 diameters or more have little or no interference effect (fig. 5). For smaller spacings the interference drag increases gradually with decreases in spacing down to a spacing of about 2.5 diameters. For spacings less than 2.5 diameters the interference increases rapidly with reduction in spacing to a maximum value not determined in these tests because of excessive vibration. The magnitude of the interference drag at these small spacings may be ten or more times the drag of a single strut. Another significant fact is that each size of strut defines a separate curve, suggesting a Reynolds Number effect; but with the exception of struts spaced very close together, the drag coefficient is constant for all air speeds for each strut size, indicating the reason for the difference to be elsewhere. Wind-tunnel conditions influencing the results on cylinders as previously noted may possibly be responsible for these discrepancies.

Probably the most reasonable explanation for the cause of interference between two streamline struts

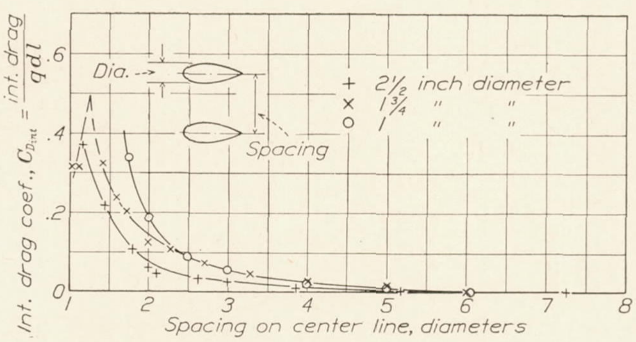


FIGURE 5.—Effect of side-by-side spacing on interference drag of streamline struts. Navy no. 1 strut section, fineness ratio, 3. Air speed, 80 m.p.h.

spaced side by side is that the flow cannot follow the contour of the adjacent strut surfaces. Streamline struts spaced relatively close together form an effective venturi having a high degree of divergence. Upon passing the throat of the venturi the air flow does not expand sufficiently to fill the diverging passage. Owing to losses in the boundary layer, sufficient kinetic energy is lacking in the air stream to overcome the increasing pressure in the expanding jet.

Cylinders.—As is the case for streamline struts, the interference drag of cylinders side by side increases gradually with reduction of spacing for intervals less than 5 or 6 diameters (fig. 6); but instead of rapidly increasing for spacings less than 2.5 diameters, the interference drag varies between wide ranges of positive and negative values. For 2.5- and 1.75-inch cylinders a critical region exists at about 1.75-diameter spacing, where the interference drag may be either positive or negative, depending, of course, on the flow pattern existing at the time. Apparently the type of flow changes rapidly with a change in spacing; it may even change while the spacing is held constant. The rapid decreases in drag are probably due to the fact that the trailing vortices behind the two cylinders join or interlock for certain spacings to form only a single path, resulting in a decreased amount of disturbed air. For spacings less than 1.25 diameters the interference drag increases very rapidly with decreases in spacing.

STRUTS IN TANDEM

Streamline struts.—Figure 7 shows the interference drag resulting from spacing streamline struts in tandem. Since separate measurements were made on each strut, a more general picture was obtained of the flow conditions than if the struts had been combined in one unit. Several noteworthy results were obtained from these tests. First, the drag of the rear strut is increased to some extent by the presence of the front strut for all spacings tested, the magnitude being much greater for small spacings. Second, the drag of the front strut is reduced an almost equal amount by the presence of the rear strut. For spacings less than 4.5 diameters the net front-strut reaction is actually in an upstream direction. Third, considering the two struts as a unit, the drag is increased a small amount throughout the range, reaching a maximum at about 4 diameters. Fourth, the agreement of results is excellent for all sizes of struts tested.

The probable reason for the relatively high upstream force on the front strut and the downstream force on the rear strut is the presence of a region of increased pressure head between the struts, gained at the expense of velocity head.

Cylinders.—The results of tandem-cylinder tests are somewhat different from those of tandem streamline struts (fig. 8), in that the drag of the rear cylinder is decreased in the presence of the front cylinder, while the drag of the front cylinder is not greatly affected by the presence of the rear cylinder. The magnitude of interference does not change appreciably for spacings greater than 4 diameters. For smaller spacings the drag of the rear cylinder decreases rapidly with decreases in spacing. For spacings less than 3 diameters the rear-cylinder reaction is forward. For spacings less than 3.5 diameters the net drag of both cylinders is less than the drag of one cylinder.

The probable reason for the reduction of drag of the rear cylinder is its presence in the turbulent wake of the front cylinder. The effect of turbulent flow on the drag of cylinders is well known (reference 6). However, turbulence alone will not explain the decrease in drag for small spacings. For these spacings the vortices produced by the front cylinder probably partly encircle the rear cylinder, impinging on the back surface with sufficient force to produce a forward reaction.

TANDEM STRUTS FAIRED TOGETHER

Streamline struts.—The drag of tandem streamline struts is materially reduced for spacings less than 10 diameters by fairing them with the flat-sided fairing (fig. 9). Throughout the practical range the drag is proportional to the spacing of the struts. For spacings greater than 10 diameters it is impractical to fair struts by this method.

Cylinders.—Although an additional decrease in drag may be obtained for tandem streamline struts by enclosing them in a streamline fairing, this method of fairing was confined to cylinders. However, for most cases the same streamline fairing used for cylinders will also fit streamline struts. Hence, the curve (fig. 9) illustrating the variation of drag with spacing for cylinders faired together with a streamline section also applies, in general, to tandem streamline struts. It is noteworthy that this type of fairing is materially better than the flat-sided type in that the drag is considerably lower throughout the range and the maximum practical spacing is increased to about 12 diameters.

The method of obtaining this curve was not direct because it was impossible to determine the dimensions of the minimum-drag fairing for each strut spacing without first testing a series of different thickness sections. The drag of a complete series of fairings, covering the practical range of cylinder diameter-spacing ratios, was calculated from the data of tests on Navy no. 1 struts of different fineness ratios (fig. 3). Figure 10 shows the fairing fineness ratio at which minimum drag occurs for different cylinder spacings.

Figure 11 is a working chart for the determination of dimensions for tandem-cylinder fairings having minimum drag. To use the chart one need know only the cylinder or tube spacing in terms of cylinder diameter. The fairing chord may be read directly from the opposite side of the chart and the section thickness from the abscissa. With these dimensions the section ordinates may be calculated from table I. In case the cylinders are of unequal size the average should be taken. This method works out fairly well for cylinders of nearly the same size but may err somewhat for great differences in size. The chart is also applicable to streamline struts, providing that the diameters of the struts be assumed as slightly larger than they are. This modification will allow the necessary clearance for the nose and tail of the struts.

A STREAMLINE STRUT INTERSECTING A FLAT SURFACE

The results of tests on a streamline strut intersecting a flat surface at various angles are given in figure 12. Interference drag is given in terms of the equivalent drag of a length of strut. Drag or interference-drag coefficients are not applicable because of the lack of a length dimension. With the strut perpendicular to the 25.25-inch chord plane the interference drag is zero, but it increases gradually with decreases in angle between strut and plane. For an angle of 20° the interference drag is equal to the drag of a strut 14 diameters long, or in this case 31.5 inches.

tion in plane chord. Any direct application of these results to design should be tempered with judgment. These tests are probably more valuable for demonstrating flow conditions than for any general application.

Table II shows the results from some tests on fairing the intersection between plane and strut. For the

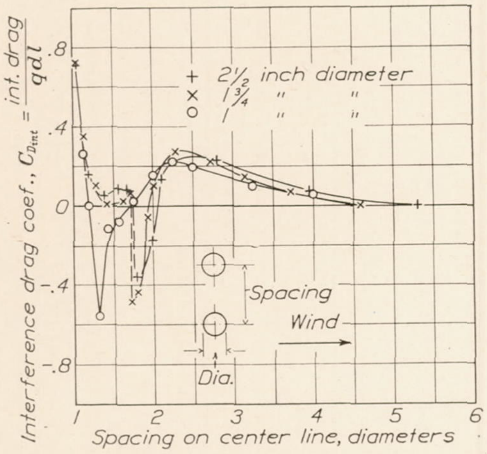
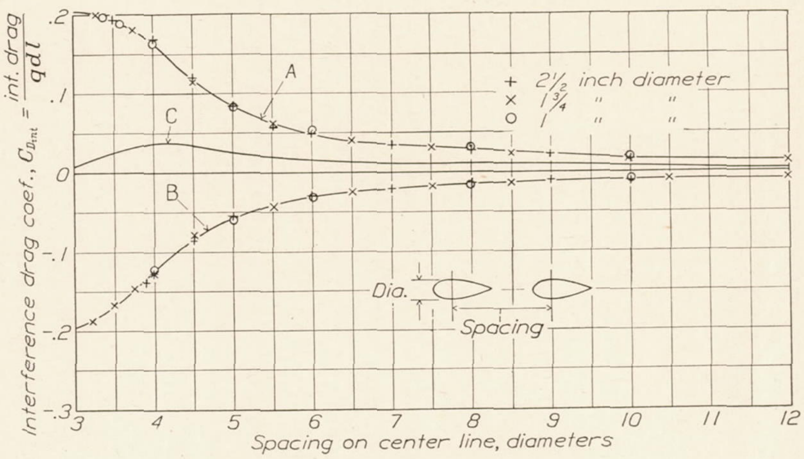
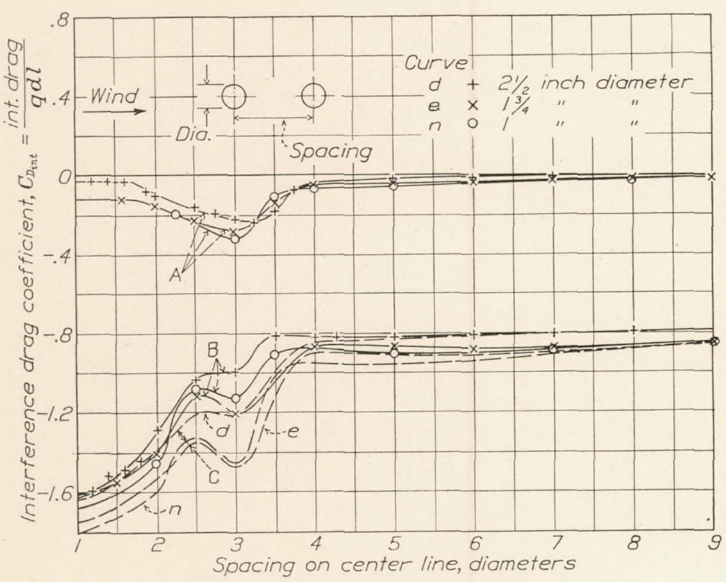


FIGURE 6.—Effect of side-by-side spacing on interference drag of cylinders. Air speed, 80 m.p.h.



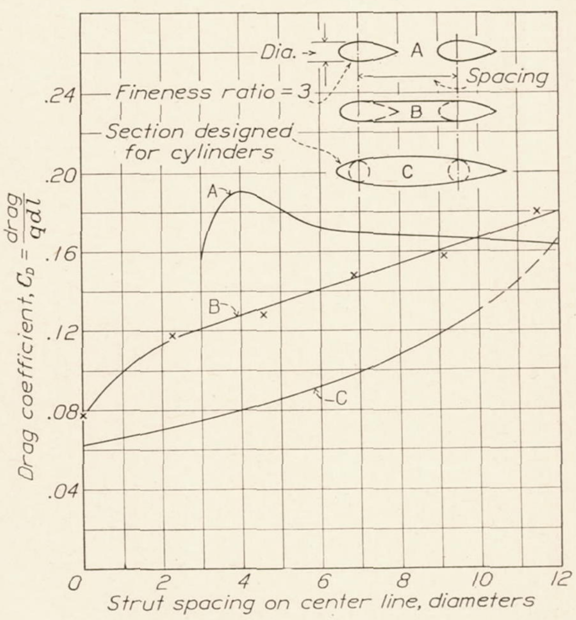
Curve A, rear strut in presence of front strut.
Curve B, front strut in presence of rear strut.
Curve C, total interference drag.

FIGURE 7.—Effect of tandem spacing on interference drag of streamline struts. Navy no. 1 strut section, fineness ratio, 3. Air speed 80 m.p.h.



Curve A, front cylinder in presence of rear cylinder.
Curve B, rear cylinder in presence of front cylinder.
Curve C, total interference drag.

FIGURE 8.—Effect of tandem spacing on interference drag of cylinders. Air speed, 80 m.p.h.



Curve A, streamline struts in tandem.
Curve B, struts faired together with parallel-sided fairing.
Curve C, drag of Navy no. 1 strut of optimum fineness ratio for enclosing cylinders.

FIGURE 9.—Effect of fairing together tandem struts.

It is interesting to note the increases in interference with decreases in the chord of the plane. For the 17.25-inch plane with a strut setting of 90° the interference drag is equal to the drag of a strut about 3 diameters long, and for the 9.25-inch plane to one of 9 diameters. Evidently the chord of the plane materially affects the flow, increasing the interference with reduc-

strut mounted perpendicular to the 25.25-inch plane the interference drag is shown to be zero if the fitting is not exposed. Fillets of the usual type failed to reduce the drag, and even increased the drag for the fillet of largest radius.

With the strut inclined 20° to the 25.25-inch plane, the attempt to reduce the interference by modifying

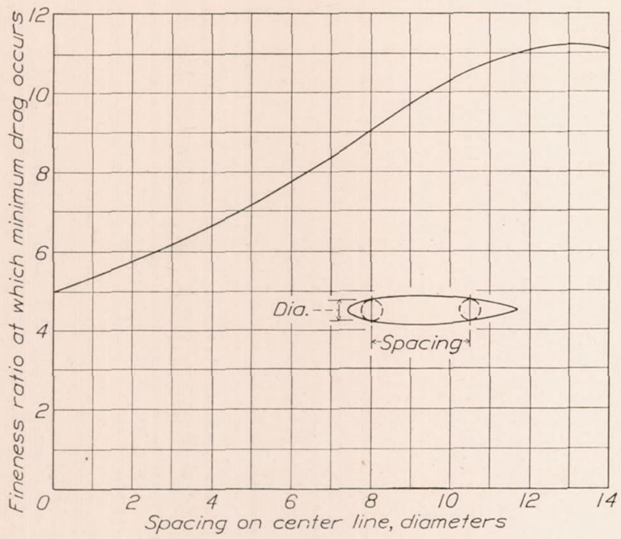


FIGURE 10.—Best fineness ratio for Navy no. 1 strut section used for fairing tandem cylinders.

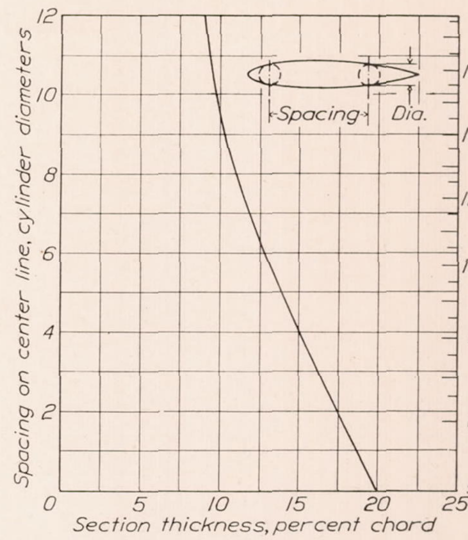


FIGURE 11.—Working chart for determining dimensions of tandem-strut fairings of minimum drag. Navy no. 1 strut section.

NOTE.—For tubes of unequal size, use average.

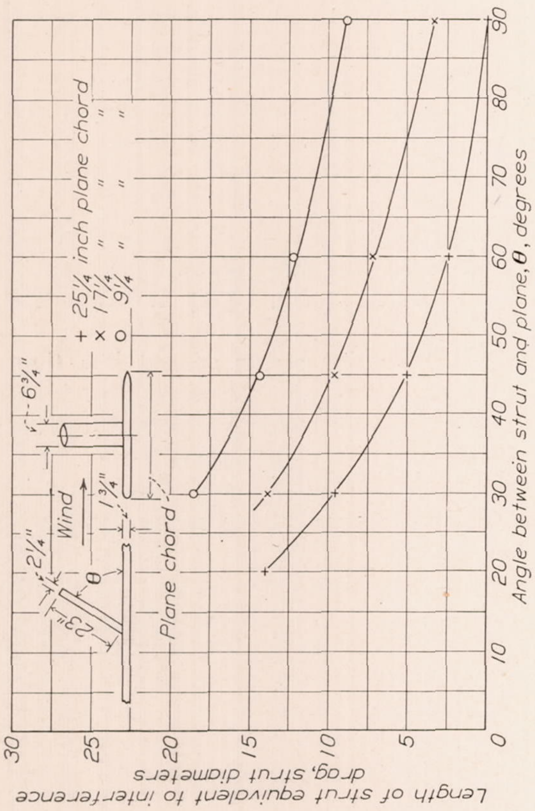


FIGURE 12.—Interference drag of a streamline strut intersecting planes of various chords at different angles. Air speed, 80 m.p.h.

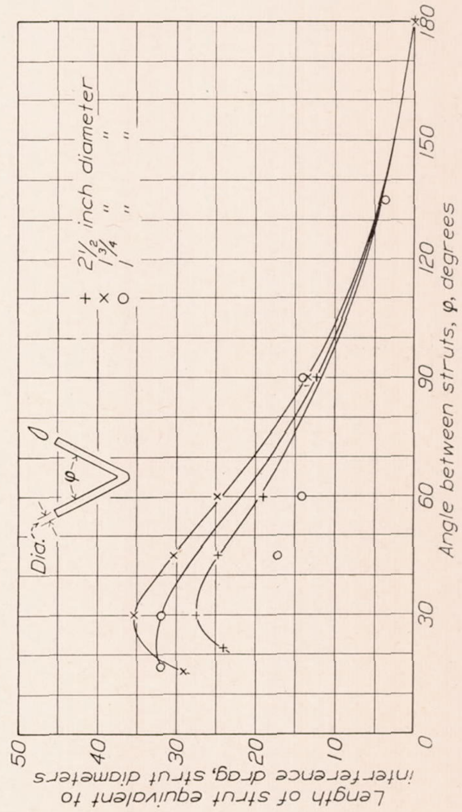


FIGURE 13.—Interference drag of streamline struts intersecting at various angles. Navy no. 1 strut section, fineness ratio, 3. Wind axis perpendicular to plane of struts. Air speed, 80 m.p.h.

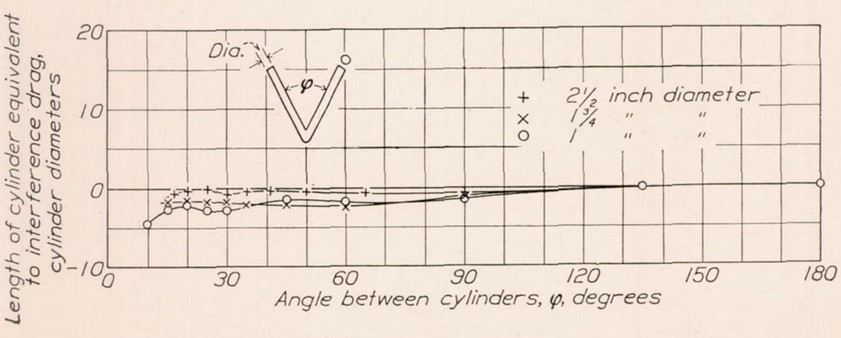


FIGURE 14.—Interference drag of cylinders intersecting at various angles. Wind axis perpendicular to plane of cylinders. Air speed, 80 m.p.h.

the effect of the acute angle with the usual type of constant-radius fillets failed. However, the interference drag was reduced 31 percent by the modification designated "1" on the sketch. This modification was considered to be of practical value because the strut fitting is often relatively small in comparison to the strut diameter, allowing a modification of this type to be made. Modification 1 also reduced the interference drag for the strut inclined 30° to the 17.25-inch plane. Furthermore, fillets reduced the drag even more, amounting to a total reduction of interference drag of 50 percent. With the strut inclined 30° to the 9.25-inch plane modification 1 reduced the interference drag 15 percent. A fillet failed to decrease the drag further.

STRUTS INTERSECTING TO FORM A V

Streamline struts.—Figure 13 shows the interference resulting from streamline struts intersecting at various angles to form V's. The interference was assumed to be equal to zero when the struts were placed end to end, forming one continuous strut. With reduction of the angle between the struts the interference increases fairly uniformly for all three sizes of models tested, reaching a maximum at about 30°. The probable reason for the reduction in interference for angles less than 30° is the rapid overlapping of the struts near the hinge point, inasmuch as the axis of rotation lies on the strut center lines. The maximum value of interference is equal to the drag of a strut from 27 to 35 diameters long, depending upon the size of the strut. For the 2.5-inch strut, this amounts to an equivalent strut length of 80 inches.

The conditions in these tests that give rise to interference are very similar to those encountered for struts spaced side by side, in that the surfaces of the struts which face each other are divergent. However, in these tests there is the additional effect of the acute angle, which probably increases the interference.

Table III shows the results of some miscellaneous fillet tests made on intersecting streamline struts. Because of the small differences in forces it was impossible to obtain very satisfactory results. For the 1 by 3 inch strut, fillets were found to have detrimental effects, increasing the interference as much as 51 percent. For the larger struts, fillets consistently reduced the interference for all angular settings of the struts tested.

Cylinders.—The interference drag of cylinders intersecting at various angles is negligible, as can be seen from figure 14.

GENERAL REMARKS

Although these tests furnish some interesting and usable data on the interference of struts in various combinations, this particular branch of the study of interference deserves much more consideration. There are other basic strut combinations which could be tested to advantage, and the relationships between interference, turbulence, tunnel speed, and model size could be more fully studied with profit.

CONCLUSIONS

The results of this investigation indicate the following:

1. Streamline struts spaced side by side 5 diameters apart or more have little or no interference. For closer spacings the interference drag increases rapidly with reduction of the interval.
2. Cylinders spaced side by side 5 diameters apart or more have practically no interference; for spacings less than 5 diameters the interference may be highly favorable or unfavorable, depending upon the size and spacing of the cylinders.
3. When streamline struts are placed in tandem the drag of the front strut is decreased by the presence of the rear one, while the drag of the rear strut is increased by the presence of the front one. This effect exists for all spacings tested, but the magnitude increases rapidly for spacings less than six times the strut thickness. The resultant interference drag for the combination is unfavorable throughout the range.
4. When cylinders are placed in tandem the drag of the front cylinder is but little affected by the presence of the rear one, while the drag of the rear cylinder is greatly reduced by the presence of the front one. The resultant interference is highly favorable for all spacings tested.
5. Tandem streamline struts spaced less than 10 diameters apart may be faired together to advantage with a flat-sided section, and to a greater advantage by encasing the struts in a streamline fairing.
6. The interference drag of a streamline strut intersecting a plane of finite thickness increases with a decrease in the chord of the plane, within the range tested, and also with a decrease in the angle between strut and plane.
7. For streamline struts intersecting to form a V and lying in a plane perpendicular to the air stream the interference drag increases with decreasing included angle, reaching a maximum value at about 30°. For angles less than 30° the interference decreases with decreasing included angle.
8. For cylinders intersecting to form a V and lying in a plane perpendicular to the air stream the interference drag is negligible for all values of the included angle.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *June 5, 1933.*

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TABLE I

NAVY NO. 1 STRUT OFFSETS

% c	% d	% c	% d
1.25	26.0	35	100.0
2.5	37.1	40	99.5
5	52.5	50	95.0
7.5	63.6	60	86.1
10	72.0	70	73.2
12.5	78.5	80	56.2
15	83.6	90	33.8
20	91.1	95	19.0
25	95.9	98	7.8
30	98.8	100	0.0

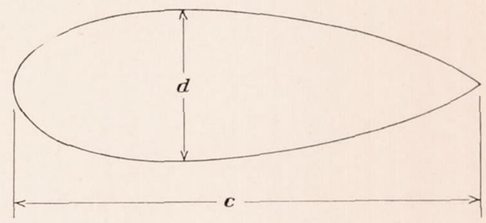
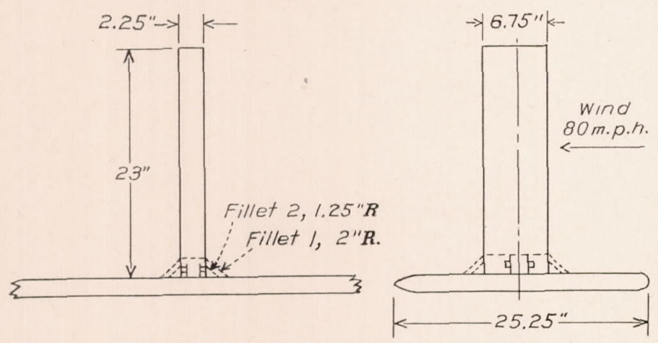
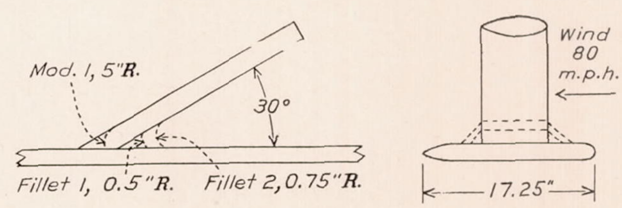


TABLE II

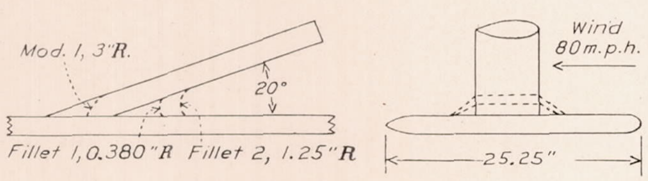
MISCELLANEOUS FAIRING TESTS ON INTERSECTION BETWEEN STREAMLINE STRUT AND PLANE



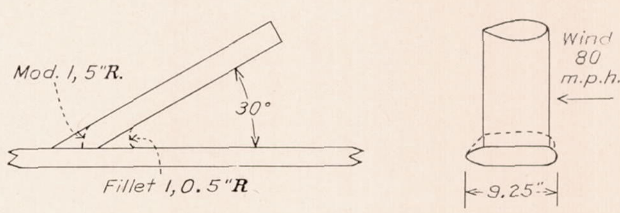
Nature of intersection	Interference drag (pound)	Equivalent strut length (diameters)	Percentage reduction by modification
Unmodified	0	0	
Bare fitting	.34	6.4	
Fillet 1	0	0	0
Fillet 2	.06	1.1	



Nature of intersection	Interference drag (pound)	Equivalent strut length (diameters)	Percentage reduction by modification
Unmodified	0.74	13.9	
Modification 1	.60	11.3	19
Modification 1 and fillet 1	.47	8.8	37
Modification 1 and fillet 2	.37	7.0	50



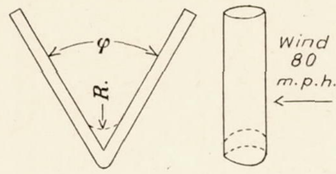
Nature of intersection	Interference drag (pound)	Equivalent strut length (diameters)	Percentage reduction by modification
Unmodified	0.75	14.1	
Modification 1	.51	9.6	31
Modification 1 and fillet 1	.51	9.6	31
Modification 1 and fillet 2	.51	9.6	31



Nature of intersection	Interference drag (pound)	Equivalent strut length (diameters)	Percentage reduction by modification
Unmodified	0.98	18.5	
Modification 1	.83	15.6	15
Modification 1 and fillet 1	.83	15.6	15

TABLE III

MISCELLANEOUS FILLET TESTS ON STREAMLINE STRUTS INTERSECTING AT VARIOUS ANGLES



Strut dimensions (inches)	φ	Fillet radius (inches)	Interference drag (pounds)	Equivalent length (diameters)	Percentage reduction with fillet
1 by 3	90°	0	0.136	14.2	----------
		.50	.103	10.7	24
1.75 by 5.25		0	.368	13.4	----------
2.5 by 7.5		0	.648	12.3	----------
		1.00	.505	9.6	22
1 by 3	60°	0	.136	14.2	----------
		.375	.205	21.4	−51
		.50	.205	21.4	−51
1.75 by 5.25		0	.682	24.9	----------
		.50	.410	14.9	40
		.75	.321	11.7	53
		1.00	.286	10.4	58
2.5 by 7.5		0	1.000	19.0	----------
		1.00	.730	13.9	27
1 by 3	45°	0	.171	17.8	----------
		.25	.225	23.4	−31
1.75 by 5.25		0	.832	30.4	----------
		.50	.613	22.4	26
		.75	.737	26.9	11
2.5 by 7.5		0	1.310	24.9	----------
		1.00	1.140	21.7	13
1 by 3	30°	0	.307	32.0	----------
		.187	.307	32.0	0
		.25	.341	35.5	−11
1.75 by 5.25		0	.968	35.3	----------
		.375	.730	26.6	25
		.625	.750	27.4	22
2.5 by 7.5		0	1.445	27.5	----------
		.75	1.210	23.0	16
		1.00	1.410	26.8	2
1 by 3	17.3°	0	.307	32.0	----------
		.187	.362	37.7	−18
1.75 by 5.25	15.5°	0	.797	29.1	----------
		.25	.750	27.4	6
		.50	.845	30.8	−6
2.5 by 7.5	21.5°	0	1.275	24.2	----------
		.50	1.240	23.6	3

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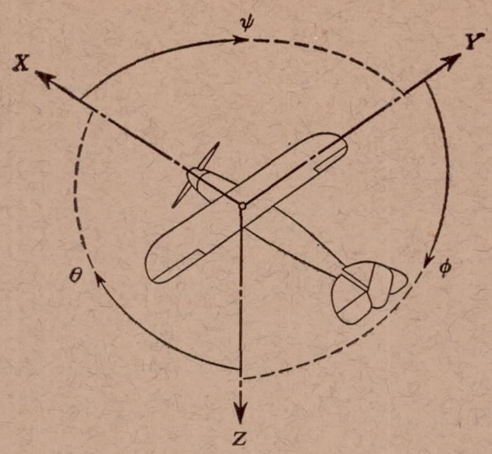

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	ϕ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	ψ	w	r

Absolute coefficients of moment

$$C_l=\frac{L}{qbS} \qquad C_m=\frac{M}{qcS} \qquad C_n=\frac{N}{qbS}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter.
p, Geometric pitch.
p/D, Pitch ratio.
V', Inflow velocity.
V_s, Slipstream velocity.
T, Thrust, absolute coefficient $C_T=\frac{T}{\rho n^2 D^4}$
Q, Torque, absolute coefficient $C_Q=\frac{Q}{\rho n^2 D^5}$

P, Power, absolute coefficient $C_P=\frac{P}{\rho n^3 D^5}$.
C_s, Speed power coefficient $=\sqrt[5]{\frac{\rho V^5}{P n^2}}$.
η, Efficiency.
n, Revolutions per second, r. p. s.
Φ, Effective helix angle $=\tan^{-1}\left(\frac{V}{2\pi r n}\right)$

5. NUMERICAL RELATIONS

1 hp. = 76.04 kg/m/s = 550 lb./ft./sec.
1 kg/m/s = 0.01315 hp.
1 mi./hr. = 0.44704 m/s
1 m/s = 2.23693 mi./hr.

1 lb. = 0.4535924277 kg
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft.