NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 522

THE DRAG OF AIRPLANE WHEELS, WHEEL FAIRINGS AND LANDING GEARS—III

By WILLIAM H. HERRNSTEIN, JR., and DAVID BIERMANN

1935

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AERONAUTIC SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Abbreviation	Unit	Abbreviation
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	horsepower (metric)		horsepower	hp.
Speed	V	{kilometers per hour	k.p.h.	miles per hour	m.p.h.
		{meters per second	m.p.s.	feet per second	f.p.s.

2. GENERAL SYMBOLS

W, Weight $= mg$

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

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

I, Moment of inertia $= mk^2$. (Indicate axis of radius of gyration k by proper subscript.)

μ, Coefficient of viscosity

ν, Kinematic viscosity

ρ, Density (mass per unit volume)

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

Specific weight of "standard" air, 1.2255 kg/m^3 or 0.07651 lb./cu.ft.

3. AERODYNAMIC SYMBOLS

S, Area

S_w, Area of wing

G, Gap

b, Span

c, Chord

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

V, True air speed

q, Dynamic 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 $C_{D_o} = \frac{D_o}{qS}$

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 m.p.h. normal pressure at 15° C., the corresponding number is 234,000; or for a model of 10 cm chord, 40 m.p.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_a, Angle of attack, absolute (measured from zero-lift position)

γ, Flight-path angle

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THE DRAG OF AIRPLANE WHEELS, WHEEL FAIRINGS, AND LANDING GEARS—III

By William H. Herrnstein, Jr., and David Biermann

SUMMARY

The tests reported in this paper conclude the investigation of landing-gear drag that has been carried out in the N. A. C. A. 20-foot wind tunnel. They supplement earlier tests (reported in Technical Report No. 485) made with full-scale dummy wheels, wheel fairings, and landing gears intended for airplanes of 3,000 pounds gross weight and include tests of tail wheels and tail skids.

For airplanes of this weight classification the results indicate that the drag of a landing gear having slight wheel-strut interference will be materially less when equipped with the proper size of streamline wheels than when furnished with low-pressure wheels. The drag of a cantilever landing gear is as low when equipped with the proper size of streamline wheels as when equipped with low-pressure wheels and the best type of wheel fairing.

Two of the landing gears tested combine, to a high degree, the structural advantages of the tripod types with the low drag of the full cantilever types.

The drag of a conventional tripod landing gear with streamline wheels can be reduced about 39 percent by careful fairing of all strut intersections.

Expanding fillets are useful in reducing landing-gear drag, especially on landing gears that are attached to wings.

The drags of tail-wheel units and tail skids are, even in the worst case, almost negligible.

INTRODUCTION

The suggestions and queries that followed the publication of reference 1 resulted in a considerable extension of the original program of the investigation of landing-gear drag. The first part of the extended program was reported in reference 2 and deals with tests of landing gears for low-wing monoplanes having a gross weight of about 16,000 pounds. The second part of the extended program is herein reported and contains information on the drag of nonretractable landing gears for airplanes of about 3,000 pounds gross weight.

Data were obtained concerning five general subjects:

1. Drag measurements of several landing gears each equipped with 21-inch and 24-inch streamline wheels in addition to the 27-inch streamline and 8.50–10 low-pressure wheels previously tested. Since the publication of reference 1 the load-carrying capacity of the streamline wheels has been changed, the 21-inch and 24-inch now overlapping at about 3,000 pounds and the 27-inch being used on heavier airplanes.
2. Development and tests of landing gears combining the best features of the cantilever and tripod types.
3. Tests of additional fairings, particularly about the wheel-strut intersections.
4. Measurement of the mutual interference between a wing and attached landing gear.
5. Measurement of the drag of a tail-wheel unit and that of several tail skids.

APPARATUS

The tests were made in the N. A. C. A. 20-foot tunnel which with its test equipment is fully described in reference 3. The method of supporting the test models on the balance is shown by figure 1.

All the test models were designed for an airplane of 3,000 pounds gross weight. The fuselage, engine, wing, and most of the landing gears used for these tests were the ones used for the tests reported in reference 1, differing only in the strut fairings and size of the wheels. The fuselage dimensions as well as the landing gear, wing, and engine locations are shown in figure 2.

Wheels.—In addition to the 8.50–10 low-pressure wheel and the 27-inch streamline wheel used for the tests of reference 1, new 21-inch and 24-inch streamline wheels were added because they are commonly used on airplanes of about 3,000 pounds gross weight in place of the 27-inch wheels, which are now being used on heavier airplanes. The wooden models of the wheels (see fig. 3) were made to a tolerance of ±1/32 inch. All tires had smooth treads.

Landing gears.—All the landing gears were designed to comply with the requirements of the Bureau of

Air Commerce, Department of Commerce, and the design outside dimensions were strictly adhered to in the fabrication of the various parts. Landing gears 1a, 1a, 11b, 15a, 15b, 15c, and 16 (see figs. 4, 5, 6, 7, 8, 9, and 10, respectively) were attached directly to the fuselage. Landing gear 13 (fig. 12) was attached to the wing. Landing gears 1a, 11a, 11b, and 13 were of the same basic types as those reported in reference 1; landing gears 15a, 15b, 15c, and 16 were types not previously tested. Dimensions for the wheel fairings used on landing gears 11a, 11b, and 13 may be obtained from reference 1.

Tail skids and tail-wheel unit.—The tail-wheel unit used in the tests was taken from service and consisted of an Air Corps tail-wheel fork and a 10 by 3–4 wheel. The principal dimensions of the unit may be obtained from reference 4. Figure 14 shows the location of this unit with reference to the test fuselage and also shows the details of tail skids 1, 2, 3, and 4. Tail skid 1 was of tripod construction with an oleo unit in the rear. Tail skid 2 consisted of two struts in tandem, one of which was an oleo unit. Tail skid 3 was of the cantilever spring-leaf type; tail skid 4 was of cantilever construction with the shock-absorber unit inside the fuselage.

TESTS

Drag and air speed were measured for all tests and additional lift measurements were taken in conjunction with the tests of landing gears 13 and 16. Landing gear 13 was the only landing gear whose drag was measured in the presence of the wing. Landing gears 11a and 13 were tested in conjunction with a radial air-cooled engine located in the nose of the fuselage but in the absence of propeller slipstream.

Landing gears equipped with four different wheels.—Landing gears 1a, 11a, 11b, 15a, 15b, and 15c were tested when equipped with 8.50–10 low-pressure wheels, and with 21-inch, 24-inch, and 27-inch streamline wheels. It was thought that such a variety of landing gears

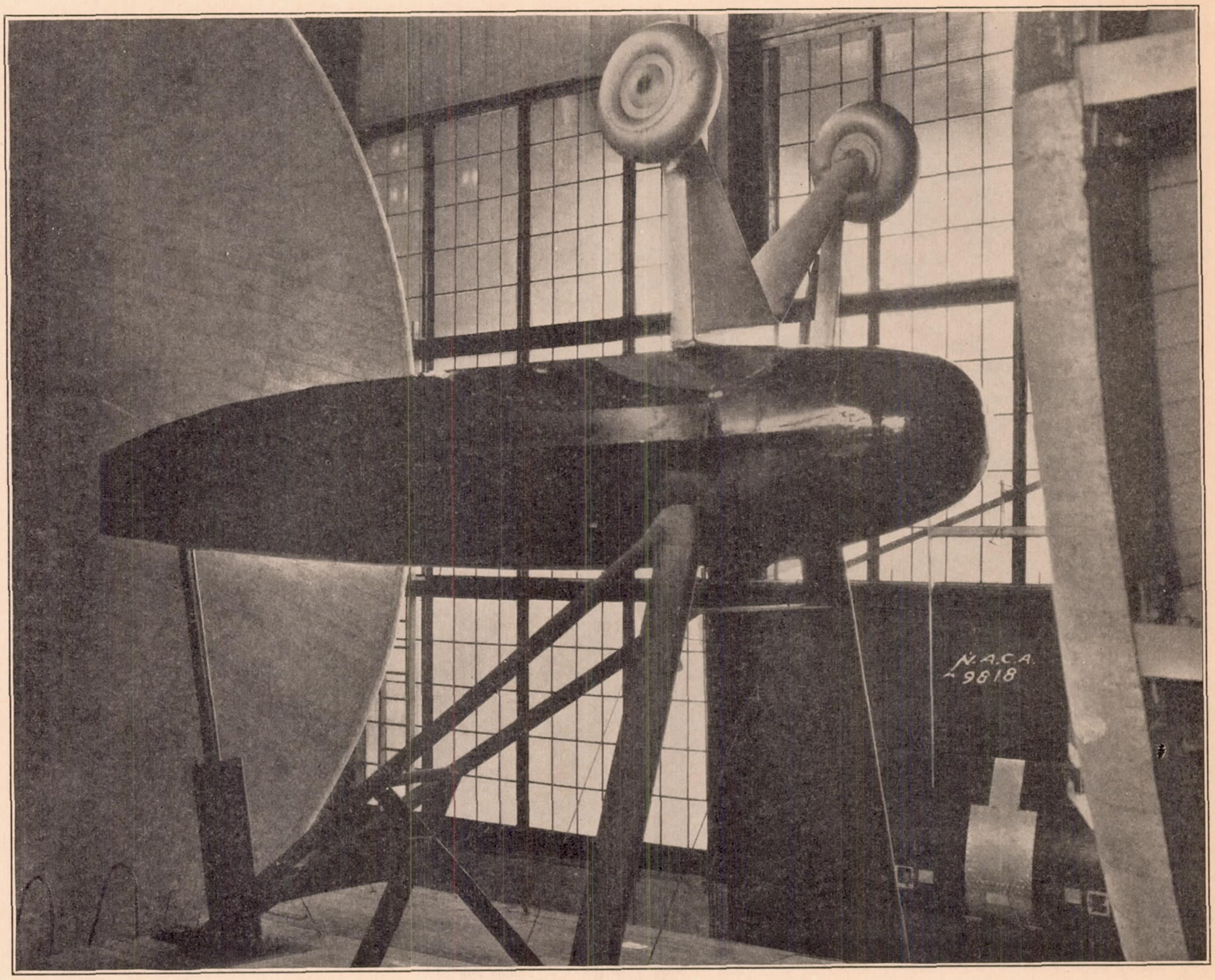


FIGURE 1.—Fuselage with landing gear 15c mounted on balance.

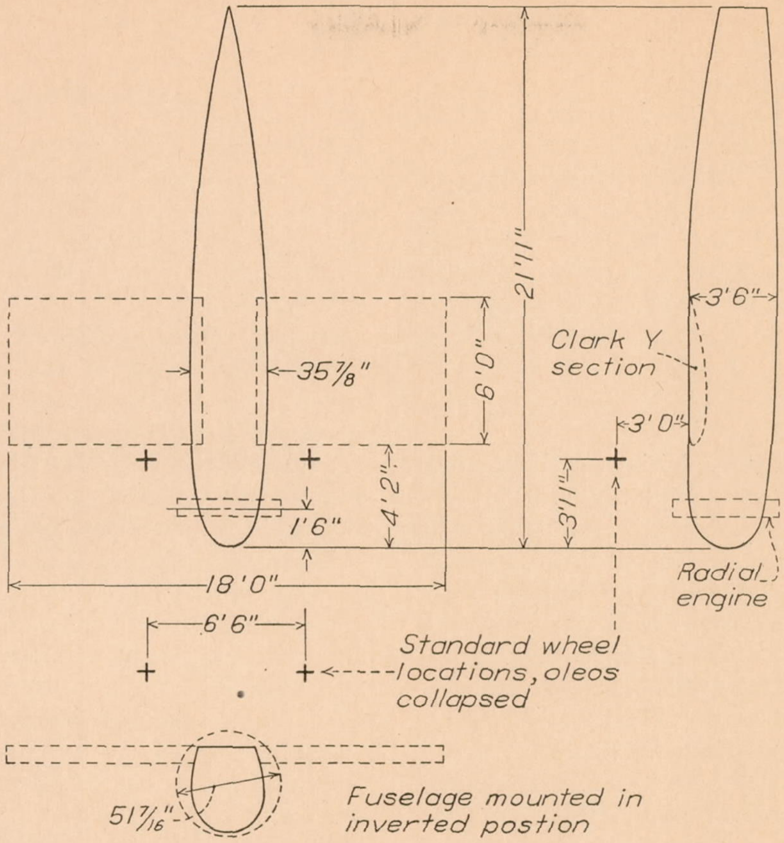
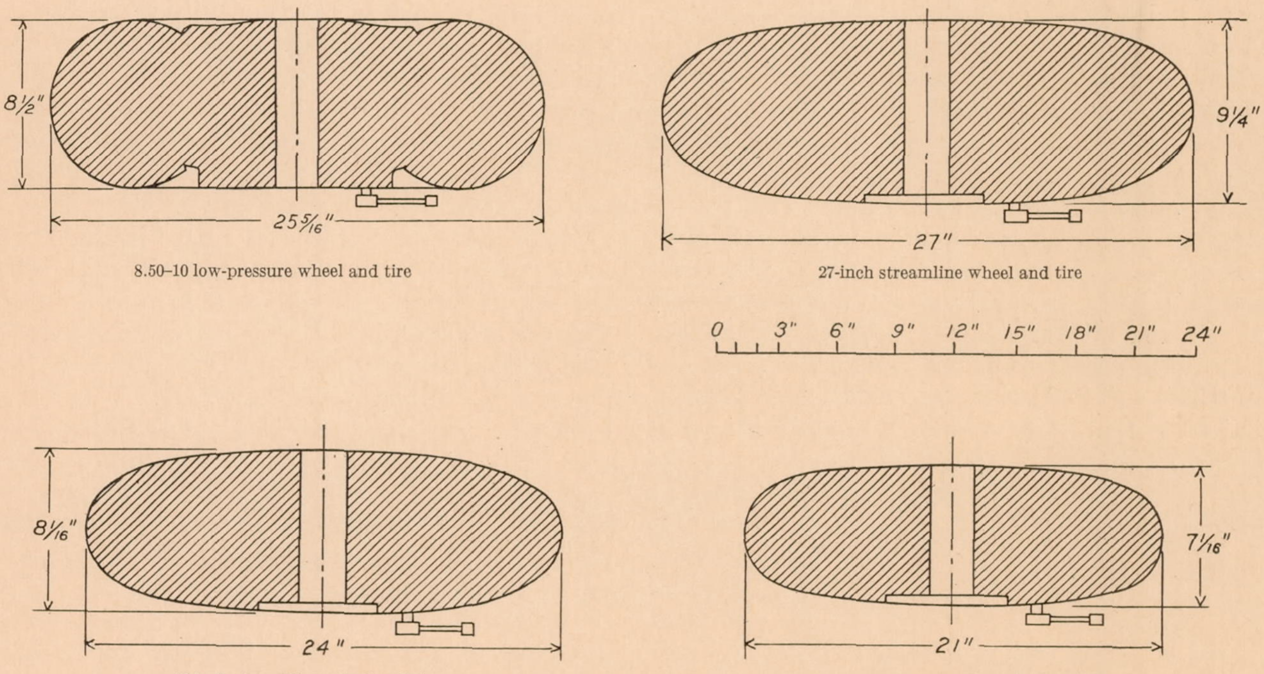


FIGURE 2.—Sketch of fuselage showing locations of wing, wheels, and engine.

NOTE.—For gears designed for a 6- by 18-foot wing (low-wing monoplane), the wheel locations are 13⅛ inches to the rear of the standard locations.



8.50–10 low-pressure wheel and tire

27-inch streamline wheel and tire

24-inch streamline wheel and tire

21-inch streamline wheel and tire

FIGURE 3.—Dimensions of wheels.

would give an indication of the relative merits of these wheels on almost any type of nonretractable landing gear for a 3,000-pound airplane.

Landing gears combining the advantages of the cantilever and tripod types.—Because the tests reported in reference 1 had indicated that the drag of conventional tripod landing gears was large because of the high interference and fitting drag, it was thought that if this part of the drag of a tripod landing gear were eliminated it would be possible to combine the light structure of such a landing gear with the low-drag features of the cantilever types. With this idea in mind, landing gears 15a, 15b, and 15c (figs. 7, 8, and 9) were designed and tested.

Landing gears with various fairings and modifications.—Landing gear 1a was tested with a long-tailed fairing at the wheel-strut intersection and then with additional fairings at the axle cross and the intersection of the landing gear and the fuselage. The drag of the landing gear was later measured with the additional fairings on but with blunt-tailed fairings replacing the long-tailed fairings at the wheel-strut intersection (fig. 4). Landing gear 13 was tested with modifications 1, 2, 3, 4, 5, and 6, which are shown in figure 12. Landing gears 15a, 15b, and 15c were tested with fairings at the wheel-strut intersections and then landing gears 15a and 15c were tested without the fairings (figs. 7, 8, and 9, respectively). The drag and lift of landing gear 16 was measured with and without an expanding fillet at the intersection of the fuselage and landing gear (fig. 10).

Mutual effect of wing and landing gear on landing-gear drag.—Lift and drag measurements were obtained for a set-up composed of the fuselage, wing set at 0°, and landing gear 13 for various angles of pitch from −5° to 6°. Similar measurements were obtained for the fuselage and wing combination with the landing gear removed. From these data the landing-gear drag with respect to the total lift was determined, thereby taking into account any changes in induced drag due to the presence of the landing gear.

Tail-wheel unit and several tail skids.—The drag of the tail-wheel unit in its original form and with modifications 1 and 2 was measured with the landing gear removed. The drag of tail skids 1, 2, 3, and 4 was also obtained. (See fig. 14.)

ACCURACY

Tests made in conjunction with the fuselage alone are estimated to be accurate to within ± 0.5 pound; tests made in conjunction with the fuselage, wing, and engine at various angles of pitch are believed to be accurate to within ± 1.0 pound. The faired lift curves are considered correct within ± 1 percent at 0° angle of pitch. The discrepancies between the results obtained in this investigation and those reported in reference 1 for similar conditions are believed to be due to differences in the set-ups made at the two different times.

RESULTS AND DISCUSSION

All drag and lift values presented in this report were taken from faired curves of drag and lift plotted against dynamic pressure. In all cases, excepting those where the forces are presented plotted against angle of pitch or lift coefficient, the values are given for 0° angle of pitch.

Landing gears equipped with four different wheels.—The results of the tests of several landing gears equipped with different wheels are given in the figures showing the landing gears and, for convenience, are summarized in table I. Some of the results obtained during the original tests presented in reference 1 are included for comparative purposes.

The results of tests of landing gear 1a (fig. 4) equipped with the 8.50–10 low-pressure wheel and the 24-inch and 27-inch streamline wheels confirm those of reference 1 in showing that the streamline wheel has no aerodynamic advantage over the low-pressure wheel unless the interference at the wheel-strut intersection is small. Unless this wheel-strut interference is small the low-pressure wheel is slightly superior.

The 8.50–10 wheel and the 21-inch, 24-inch, and 27-inch streamline wheels were used on landing gear 11a. (See fig. 5.) Since the landing gear had very small interference and total drag the streamline wheels were better than the low-pressure wheel. The drag with the 21-inch wheel was reduced to 20.0 pounds, 6.5 pounds less than that of the low-pressure wheel under the same conditions and only slightly greater than the drag with the low-pressure wheel and the best wheel fairing (wheel fairing C).

When the same wheels were used with landing gear 11b as were used with 11a the superiority of the streamline wheels was even more pronounced. (See fig. 6.) The use of the 24-inch streamline wheel resulted in a landing-gear drag equal to that with the 8.50–10 low-pressure wheel and wheel fairing A. When the 21-inch wheel was used the landing-gear drag dropped from 17.5 to 13.5 pounds. In addition to the low drag that can be obtained with the proper size of streamline wheels without wheel fairings, further advantages are presented in that the installation is lighter, less costly, and more accessible for repairs.

Tests of landing gears 15a, 15b, and 15c again demonstrate that the streamline wheel is effective in reducing the landing-gear drag, especially when the wheel-strut interference is reduced. (See figs. 7, 8, and 9.) As might be expected, the smallest streamline wheel reduces the drag the most.

Landing gears combining the advantages of the cantilever and tripod types.—Landing gears 15a, 15b, and 15c were designed and tested in an effort to

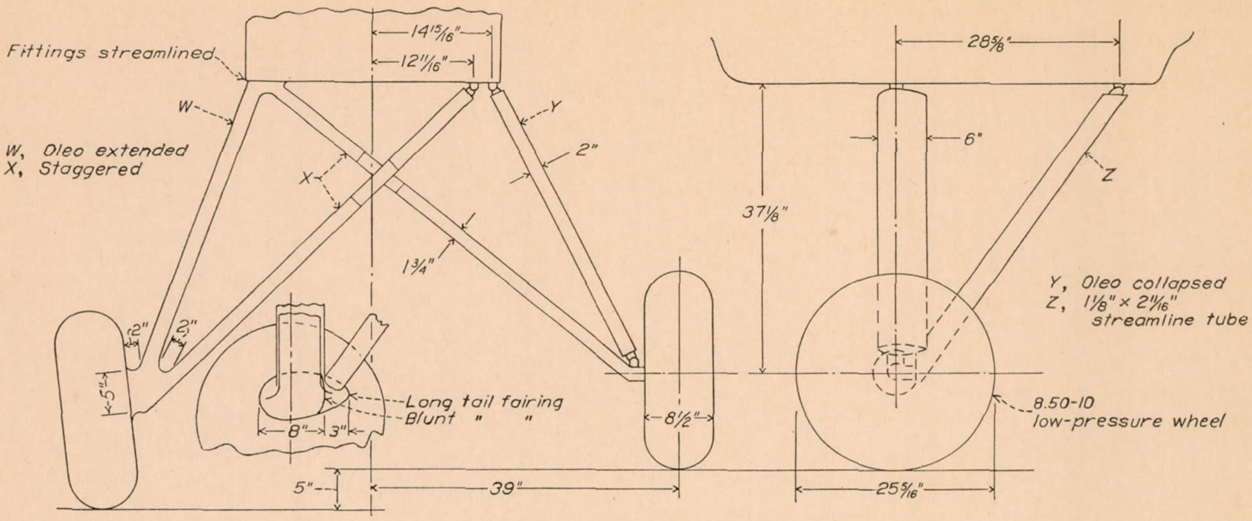


FIGURE 4.—Drag and dimensions of landing gear 1a.

Drag of landing gear at 100 m. p. h. (oleos extended):	Pounds
8.50-10 low-pressure wheels, strut intersections not faired (tests of reference 1)	42.5
24-inch streamline wheels, strut intersections not faired	44.0
24-inch streamline wheels, long-tailed fairings at wheel-strut intersections only	31.0
24-inch streamline wheels, all strut intersections streamlined, including axle cross	27.0
27-inch streamline wheels, all strut intersections streamlined, including axle cross	30.0
8.50-10 low-pressure wheels, all strut intersections streamlined, including axle cross	32.5
8.50-10 low-pressure wheels, blunt-tailed fairings at wheel-strut intersections, others unchanged	35.5
24-inch streamline wheels, blunt-tailed fairings at wheel-strut intersections, others unchanged	34.5

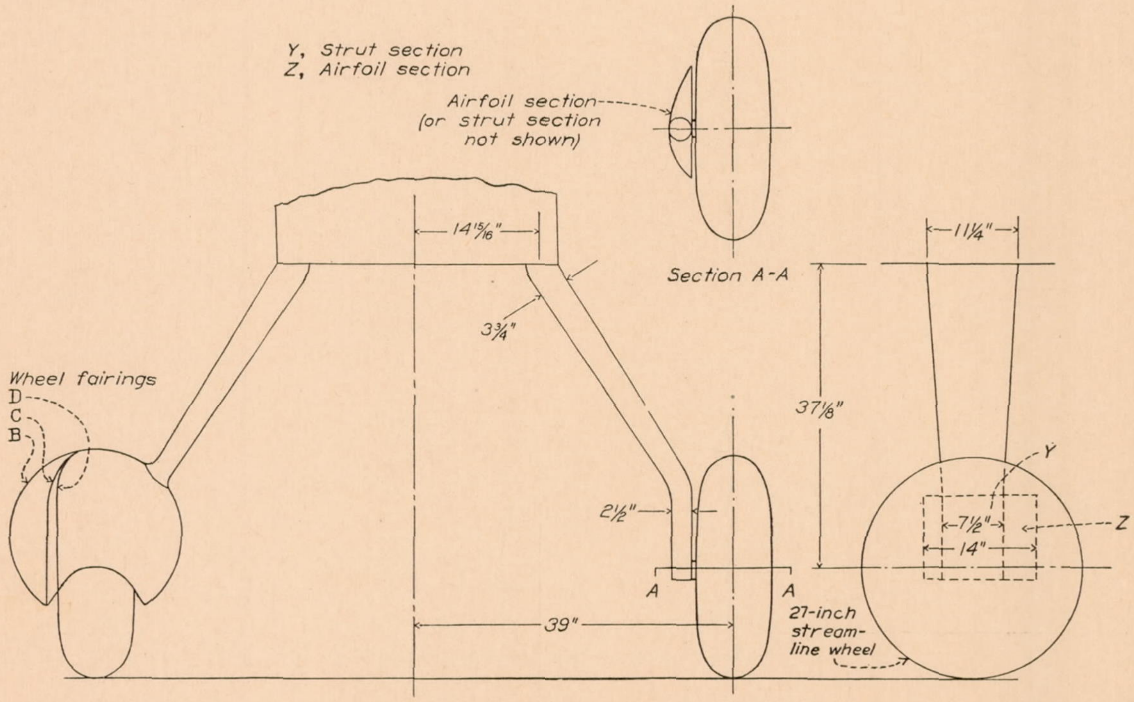


FIGURE 5.—Drag and dimensions of landing gear 11a.

Drag of landing gear at 100 m. p. h.:	Pounds
8.50-10 low-pressure wheels, wheel fairings B, no engine in fuselage (tests of reference 1)	20.5
8.50-10 low-pressure wheels, wheel fairings C, no engine in fuselage (tests of reference 1)	18.5
8.50-10 low-pressure wheels, wheel fairings C, engine in fuselage	18.0
8.50-10 low-pressure wheels, wheel fairings D, (modification D_1), no engine in fuselage (tests of reference 1)	19.5
8.50-10 low-pressure wheels, airfoil section alongside wheel, no engine in fuselage	26.5
21-inch streamline wheels, airfoil section alongside wheel, no engine in fuselage	20.0
24-inch streamline wheels, airfoil section alongside wheel, no engine in fuselage	22.5
27-inch streamline wheels, airfoil section alongside wheel, no engine in fuselage	24.5
27-inch streamline wheels, airfoil section alongside wheel, no engine in fuselage (tests of reference 1)	22.0

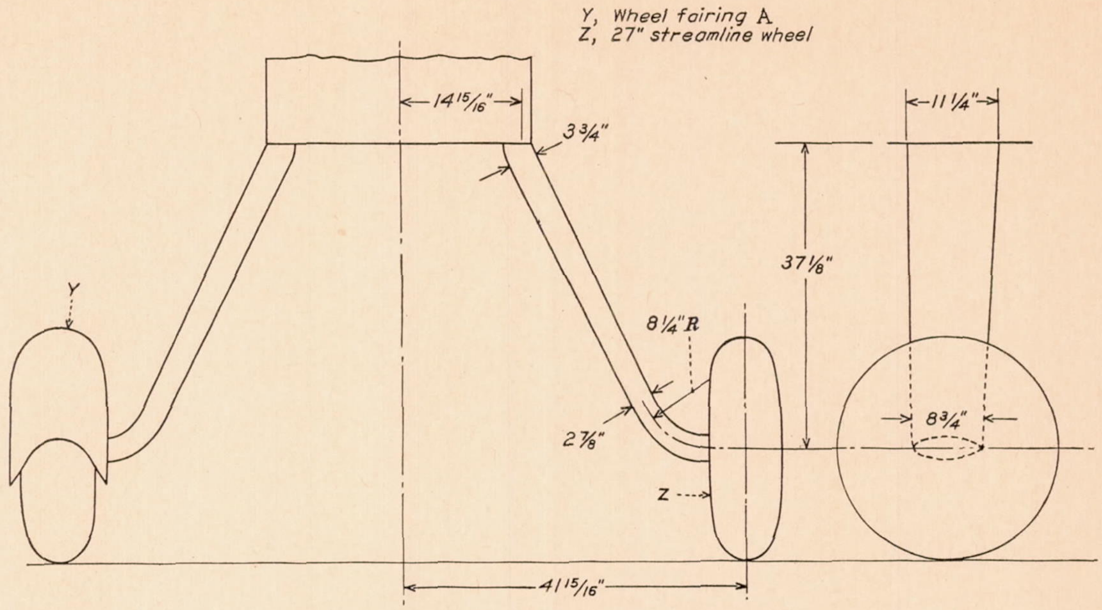


FIGURE 6.—Drag and dimensions of landing gear 11b.

Drag of landing gear at 100 m. p. h.:	Pounds
8.50–10 low-pressure wheels	24.0
8.50–10 low-pressure wheels (tests of reference 1)	23.5
8.50–10 low-pressure wheels, wheel fairings A (tests of reference 1)	17.5
21-inch streamline wheels	13.5
24-inch streamline wheels	17.5
27-inch streamline wheels	20.5
27-inch streamline wheels (tests of reference 1)	21.5

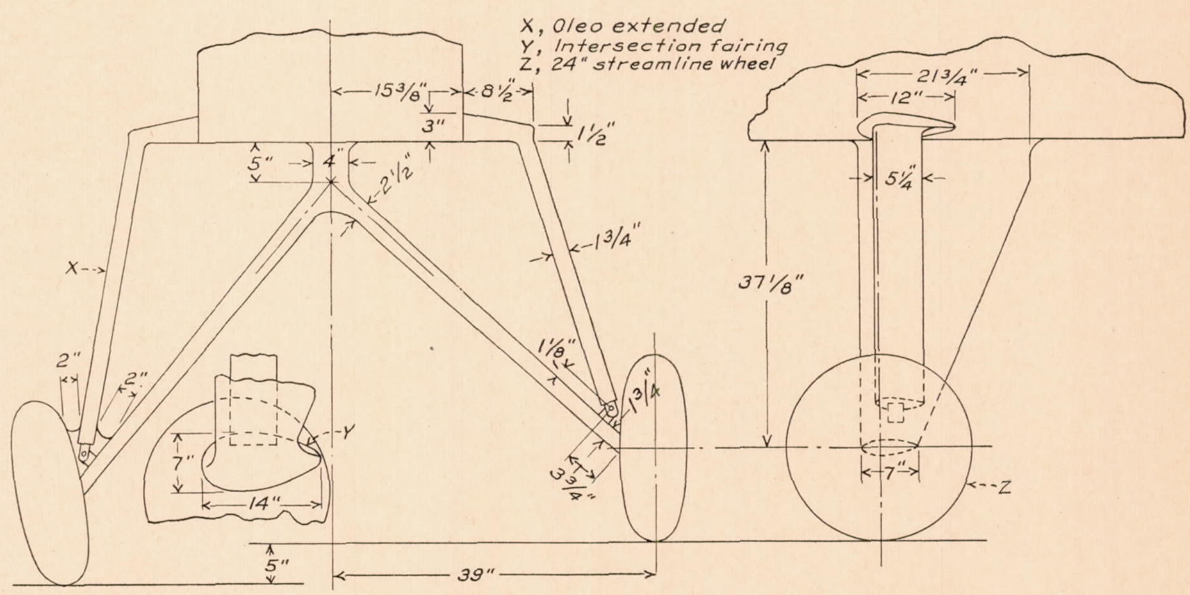


FIGURE 7.—Drag and dimensions of landing gear 15a.

Drag of landing gear at 100 m. p. h. (oleos extended):	Pounds
21-inch streamline wheels, wheel-strut intersections faired	23.0
24-inch streamline wheels, wheel-strut intersections faired	27.0
27-inch streamline wheels, wheel-strut intersections faired	30.0
8.50–10 low-pressure wheels, wheel-strut intersections faired	31.0
8.50–10 low-pressure wheels, wheel-strut fairings removed	29.0
24-inch streamline wheels, wheel-strut fairings removed	28.5

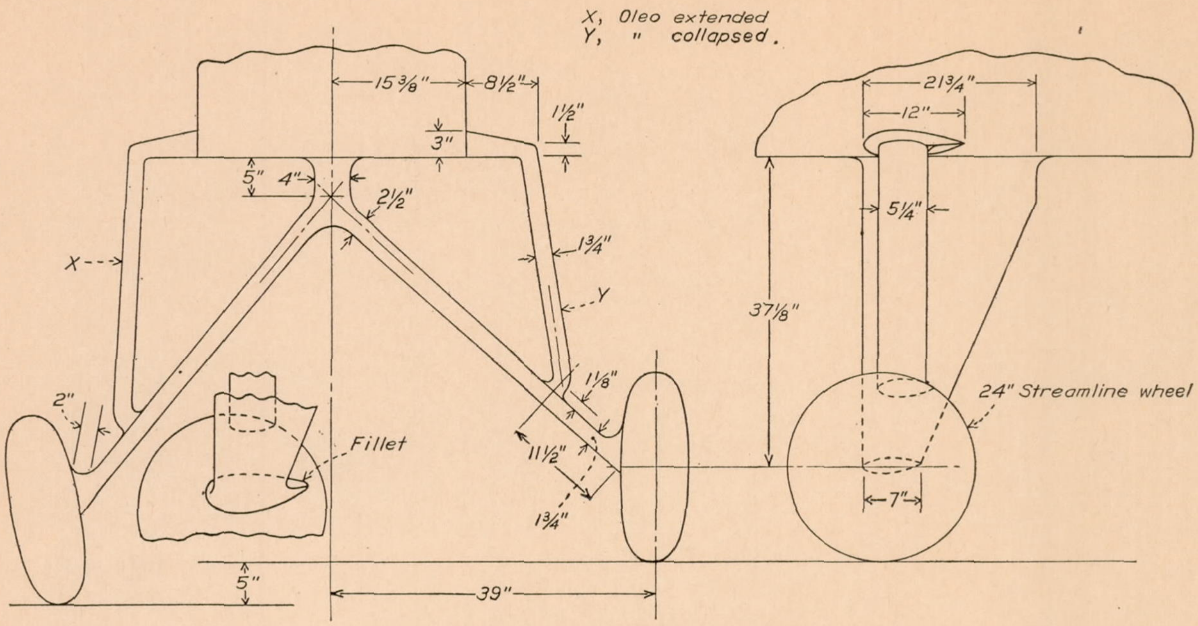


FIGURE 8.—Drag and dimensions of landing gear 15b.

Drag of landing gear at 100 m. p. h. (oleos extended):	*Pounds*
24-inch streamline wheels, all intersections filleted	22.0
8.50–10 low-pressure wheels, all intersections filleted	25.0

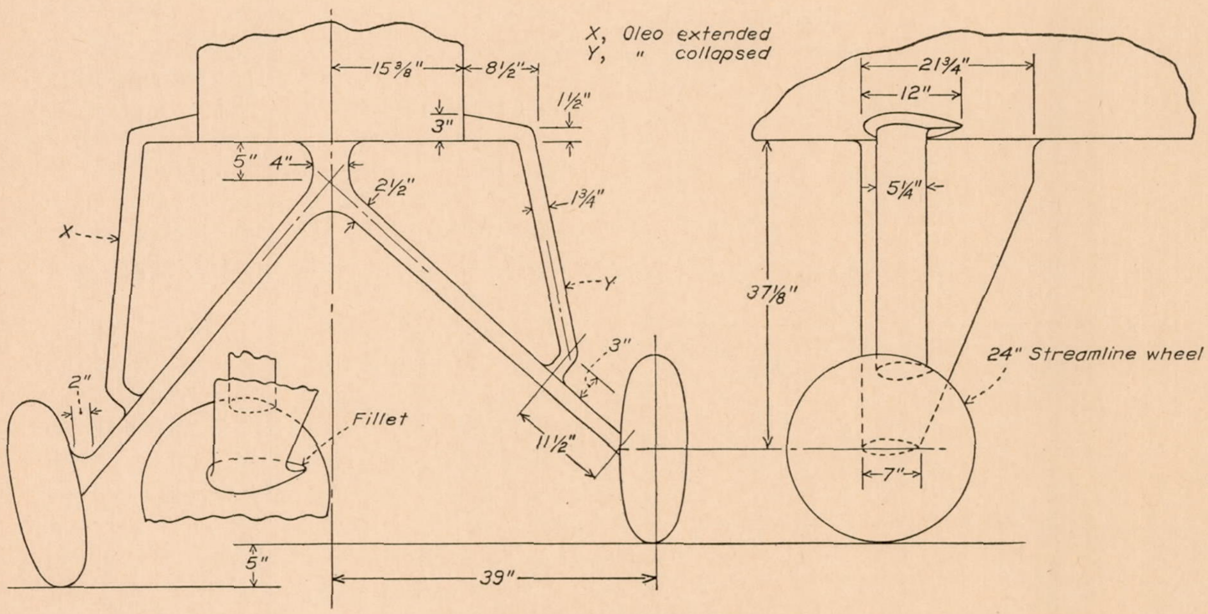


FIGURE 9.—Drag and dimensions of landing gear 15c.

Drag of landing gear at 100 m. p. h. (oleos extended):	*Pounds*
21-inch streamline wheels, all intersections faired	17.5
24-inch streamline wheels, all intersections faired	22.0
27-inch streamline wheels, all intersections faired	25.0
8.50–10 streamline wheels, all intersections faired	25.5
8.50–10 streamline wheels, wheel-strut fillet removed	27.0
24-inch streamline wheels, wheel-strut fillet removed	23.0

eliminate the high interference and fitting drag of conventional tripod landing gears and bring such landing gears into the same drag range as the cantilever types. It is apparent from figures 7, 8, and 9 that landing gear 15a with the oleo-axle intersection next to the wheel is not the equal of landing gears 15b or 15c on which the interference has been reduced by having the intersection placed a considerable distance up the axle. Landing gears 15b and 15c had practically the same drag when tested under similar conditions. Both had very low drags for tripod landing gears. With streamline wheels the drag of landing gear 15c was only about 4.0 pounds greater than that of cantilever landing gear 11b; the additional drag represents that due to the struts. (Cf. figs. 6 and 9.)

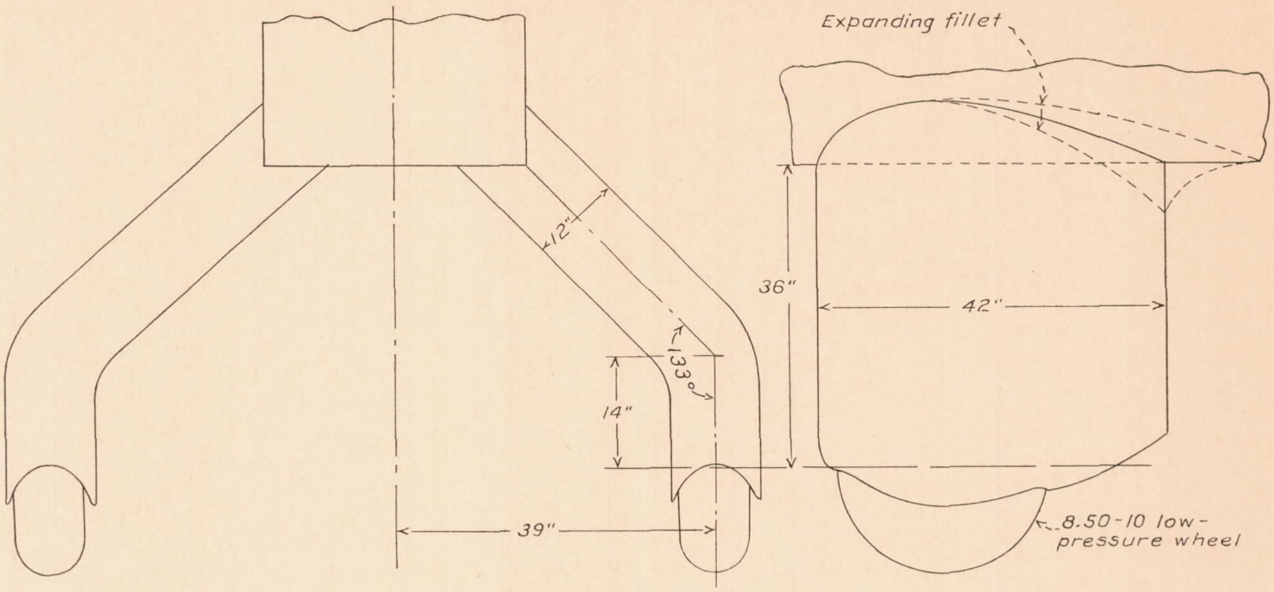


FIGURE 10.—Dimensions of landing gear 16.

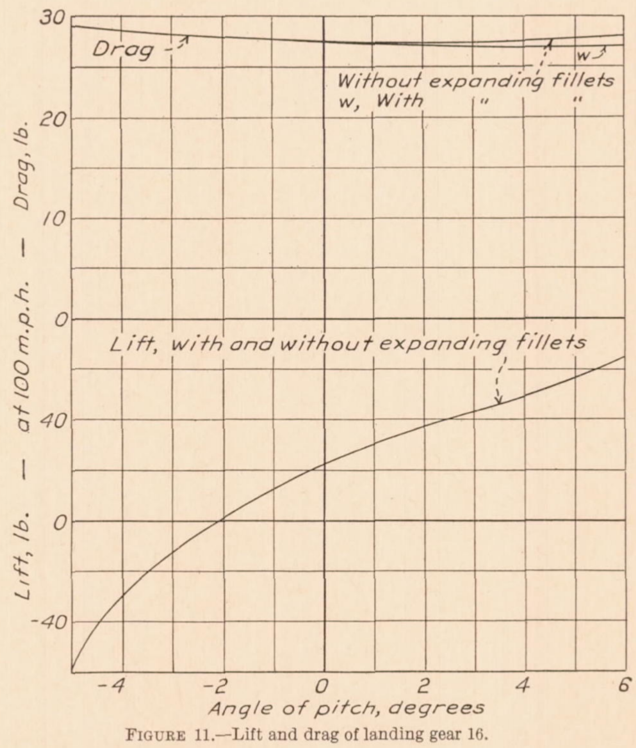


FIGURE 11.—Lift and drag of landing gear 16.

Landing gears with various fairings and modifications.—Figure 4 shows the effects of two different fairings at the wheel-strut intersection of landing gear 1a. One fairing had a long tail and the other was blunt at the rear. The long-tailed fairing was appreciably more effective in reducing the drag, as may be seen by an examination of the drag values. This fairing when used in conjunction with the 24-inch streamline wheel reduced the landing-gear drag from 44.0 pounds to 31.0 pounds thereby effecting a saving in drag of 30 percent. Fairing all strut intersections at the fuselage and also the axle cross accounted for a further decrease of 4.0 pounds.

The negligible effect of an engine on the drag of landing gear 11a with 8.50–10 low-pressure wheels and wheel fairing C is shown in figure 5.

The effects of various modifications to landing gear 13 are shown by figure 13(b). At a lift coefficient of 0.2 the drag of the original landing gear is shown to be 12.5 pounds at 100 miles per hour. The addition of expanding fillets (modification 1) reduced the drag to 11.0 pounds. When the engine was placed in the nose of the fuselage (modification 6), the drag of the landing gear dropped to 10.5 pounds. These drag values are the lowest recorded for any nonretractable landing gear tested during the investigation. When modification 2 (wheel fairing extended to wing) was made to the original landing gear, the drag was increased from 12.5 to 21.0 pounds. The addition of modifications 3 and 4 (expanding fillets of different size) to the landing gear in this condition reduced the drag from 21.0 pounds to 17.0 and 15.0 pounds for the small and large fillets, respectively. When streamline side brace struts were added (modification 5) to modifications 2 and 3 and to modifications 2 and 4, the drag was increased to 25.0 and 23.0 pounds, respectively.

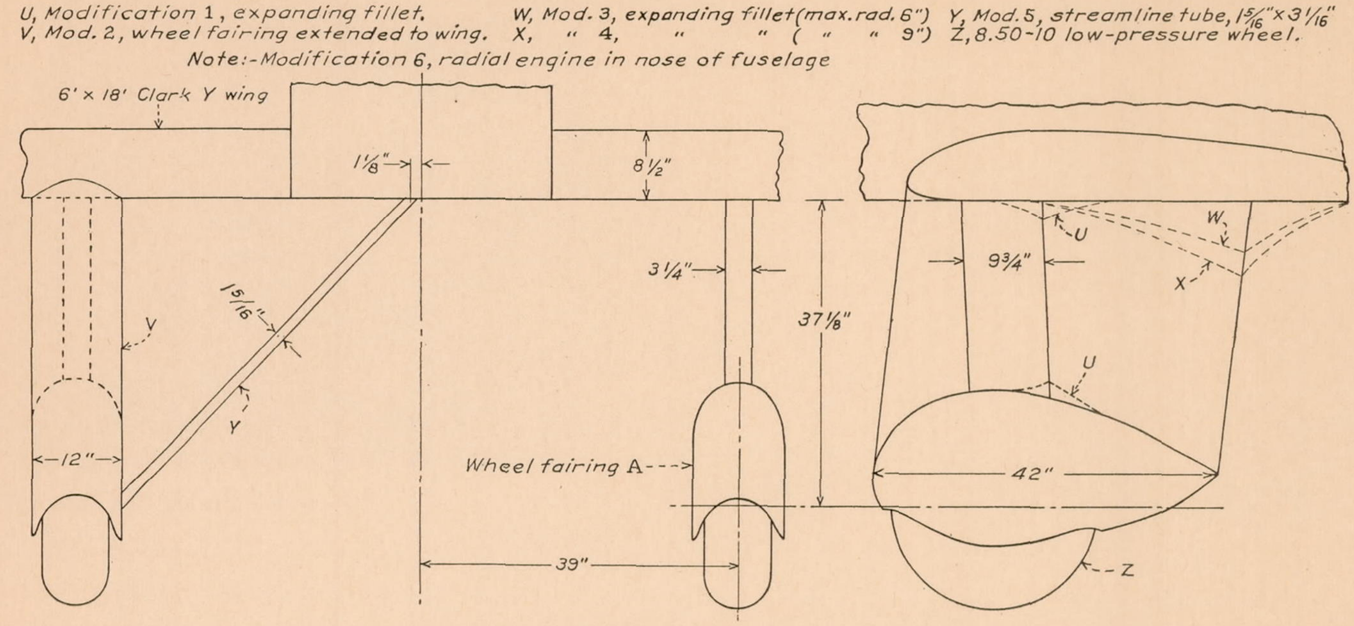


FIGURE 12.—Dimensions of landing gear 13 with various modifications.

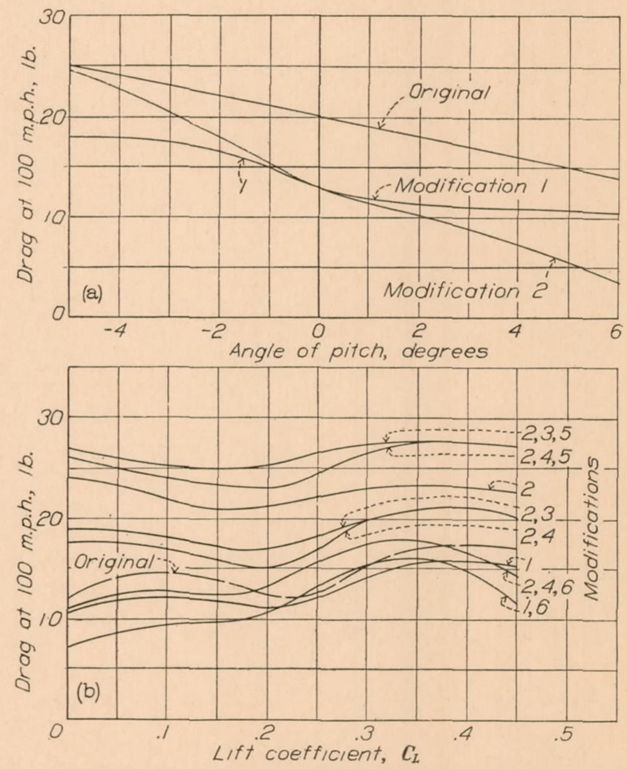
Modification 6 (engine in fuselage) in combination with modifications 2 and 4 resulted in a drag of 13.0 pounds, just 2.5 pounds greater than for the landing gear in its best condition (modifications 1 and 6). In all tests where the engine was used it was in the uncowled condition. Results reported in reference 1 showed, however, that there was little difference in the effect of the engine on landing-gear drag when the engine was uncowled and when it was equipped with N. A. C. A. cowling.

The effect of adding a wheel-strut fairing to landing gear 15a is shown in figure 7. The fairing decreased the drag but not nearly as much as did a similar fairing on landing gear 1a (fig. 4). The reason for this difference is not clear for the fairings were very much alike and so were the intersections at the wheel and struts.

Figure 9 shows how a fillet at the wheel-strut intersection affected the drag of landing gear 15c. The fillet reduced the drag 1.5 and 1.0 pounds when used with the 8.50–10 low-pressure and 24-inch streamline wheels, respectively. Although the reduction was not great, it is probably sufficient to warrant the use of such fillets.

The results of drag and lift tests made with landing gear 16 (fig. 10) are presented in figure 11. Inasmuch as this landing gear had a large lifting surface, it was thought advisable to take lift data in conjunction with the drag measurements. The landing gear was tested with and without an expanding fillet at the fuselage junction. The fillet had practically no effect on the lift and little effect on the drag. The drag was higher than expected, being about 28.0 pounds at 100 miles per hour.

Mutual effect of wing and landing gear on landing-gear drag.—Figure 13 shows how the mutual effect of a wing and landing gear may affect the drag credited to the landing gear, depending upon the manner of presenting the results. Landing gear 13 (fig. 12) was used for this illustration. The curves in figure 13(a)



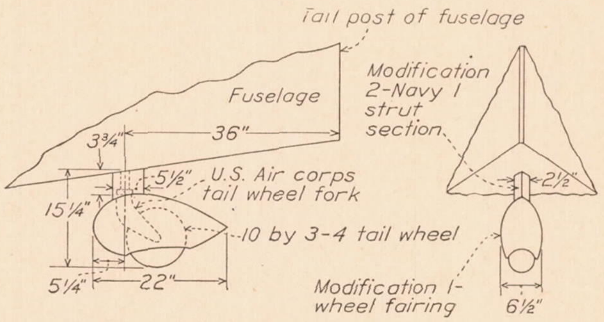
(a) Drag uncorrected for induced drag (curves from reference 1)
(b) Drag corrected for induced drag (present tests)

FIGURE 13.—Drag of landing gear 13 with various modifications.

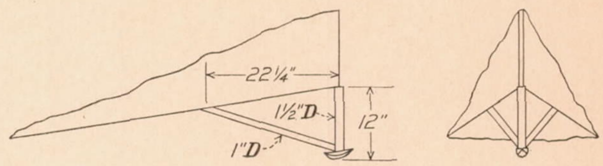
were taken from those presented in reference 1 and are based on the assumption that the landing-gear drag was the difference in drags of the set-ups, with and without landing gear, at the same angle of pitch. This method did not take into account any change in induced drag that might be caused by the presence of the landing gear. Figure 13(b), which presents the results of the present investigation, does take into account changes in induced drag because the landing-gear drag was obtained by taking the difference between the drags of the set-ups, with and without landing gear, at equal lifts.

A comparison of the two sets of curves shows that the change in induced drag should be considered, especially after modification 2 (wheel fairing extended to the wing) has been made. At a lift coefficient of 0.2, which is a reasonable assumption for the high-speed condition, the angle of pitch for the set-up without landing gear was $-0.75°$. If no induced-drag change due to the presence of the landing gear be assumed, the drag of the landing gear with modification 1 would be 14.5 pounds. By the present method the drag is shown to be 11.0 pounds. The difference is not large for this case. A similar comparison of the landing gear with modification 2 shows that drag varies from 14.5 pounds, assuming no induced-drag change, to 21.0 pounds. The results also definitely show that modification 1 is superior to modification 2, a fact not indicated in reference 1. Check tests have proved that other results reported in reference 1 where landing gears were tested in conjunction with the wing are not subject to any appreciable induced-drag correction.

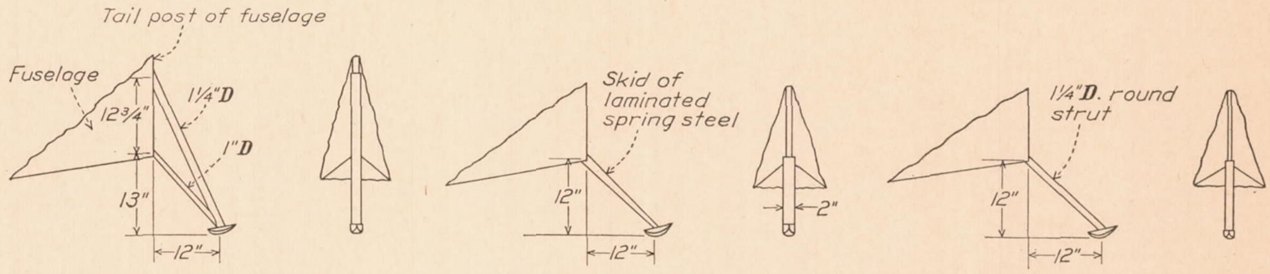
Tail-wheel unit and several tail skids.—Figure 14 gives the drag of a tail-wheel unit and several tail skids when measured with no landing gear on the fuselage. The addition of a wheel fairing to the tail wheel did not decrease the drag of the unit. Adding a streamline fairing to the fork did decrease the drag a small amount (0.5 pound). Tail skid 1, which was built of round tubing, had slightly less drag than the tail-wheel unit in its best condition, 3.0 pounds as compared with 3.5 pounds at 100 miles per hour. Tail skid 3 had the highest drag, being equal to that of the tail-wheel unit in the unfaired condition (4.0 pounds). Tail skid 2 had but 1.5 pounds drag and tail skid 4 only 1.0 pound. These results indicate that the drag of tail-wheel or skid units, even in the worst cases, is almost negligible.



Tail-wheel unit—Drag at 100 m. p. h.:
Tail-wheel unit with no fairing .... pound .. 4.0
Tail-wheel unit with modification 1 .... do 4.0
Tail-wheel unit with modifications 1 and 2 .... do 3.5



Tail skid 1—Drag at 100 m. p. h .... pound .. 3.0



Tail skid 2—Drag at 100 m. p. h .. pound .. 1.5 Tail skid 3—Drag at 100 m. p. h .... pound .. 4.0 Tail skid 4—Drag at 100 m. p. h .... pound .. 1.0

FIGURE 14.—Drag and dimensions of tail-wheel unit and various tail skids.

Effect of landing gears on high speed.—Figure 46 of reference 1 may be found convenient in computing the effects of the various types of landing gears on the high speed of an airplane.

CONCLUSIONS

The results of this investigation indicate the following to be true for airplanes of 3,000 pounds gross weight:

1. The drag of a landing gear, for which the interference between wheels and struts is small, is appreciably less with streamline wheels than with low-pressure wheels of equal load-carrying capacity. When the wheel-strut interference is high the drag of a landing gear with streamline wheels is greater.

2. A low-drag cantilever landing gear has about the same drag when equipped with the correct size of streamline wheel as when equipped with the low-pressure wheel and the best type of wheel fairing.

3. By careful design to eliminate acute angles between the members and by fairing the fittings, the drag of a tripod landing gear can be made to approach that of a cantilever landing gear without any marked increase in weight.

4. The drag of a conventional tripod landing gear with streamline wheels may be reduced as much as 39 percent by carefully fairing the strut intersections.

5. Expanding fillets are useful in reducing landing-gear drag, especially on landing gears that are attached to wings.

6. The drag of tail-wheel units and tail skids is, even in the worst cases, almost negligible.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *November 21, 1934*.

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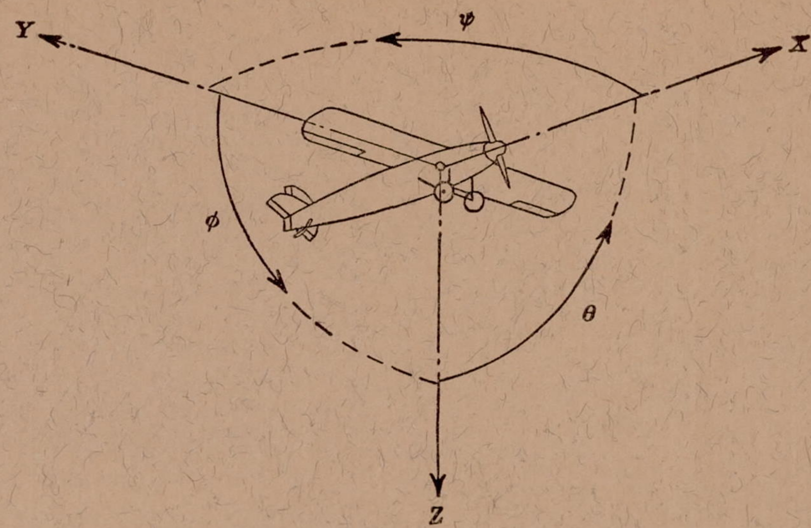
TABLE I.—THE DRAG AT 100 M. P. H. OF VARIOUS LANDING-GEAR AND WHEEL ARRANGEMENTS

[8.50–10 low-pressure wheels; 21-inch, 24-inch, and 27-inch streamline wheels]

Landing-gear and wheel arrangement	Drag	Landing-gear and wheel arrangement	Drag
	Pounds		*Pounds*
Gear 1a with wheel-strut intersections unfaired:		Gear 15a unmodified:	
24-inch wheels	44.0	24-inch wheels	28.5
8.50–10 wheels, tests of reference 1	42.5	8.50–10 wheels	29.0
Gear 1a with long-tailed fairings at wheel-strut intersections:		Gear 15a with fairings at wheel-strut intersections:	
24-inch wheels	31.0	21-inch wheels	23.0
Gear 1a with long-tailed fairings at wheel-strut intersections and fairings at all other strut intersections, including axle cross:		24-inch wheels	27.0
24-inch wheels	27.0	27-inch wheels	30.0
27-inch wheels	30.5	8.50–10 wheels	31.0
8.50–10 wheels	32.5	Gear 15b with fairings at wheel-strut intersections and all other strut intersections:	
Gear 1a with blunt-tailed fairings at wheel-strut intersections and fairings at all other strut intersections, including axle cross:		24-inch wheels	22.0
24-inch wheels	34.5	8.50–10 wheels	25.0
8.50–10 wheels	35.5	Gear 15c with fairings at all intersections except the wheel-strut intersection:	
Gear 11a with 14-inch chord airfoil along the side of wheels:		24-inch wheels	23.0
21-inch wheels	20.0	8.50–10 wheels	27.0
24-inch wheels	22.5	Gear 15c with fairings at wheel-strut intersections and all other strut intersections:	
27-inch wheels	24.5	21-inch wheels	17.5
27-inch wheels, tests of reference 1	22.0	24-inch wheels	22.0
8.50–10 wheels	26.5	27-inch wheels	25.0
Gear 11b unmodified:		8.50–10 wheels	25.5
21-inch wheels	13.5		
24-inch wheels	17.5		
27-inch wheels	20.5		
27-inch wheels, tests of reference 1	21.5		
8.50–10 wheels	24.0		
8.50–10 wheels, tests of reference 1	23.5		



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

$C_l = \frac{L}{qbS}$ (rolling) $\quad C_m = \frac{M}{qcS}$ (pitching) $\quad C_n = \frac{N}{qbS}$ (yawing)

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 $= \sqrt[5]{\frac{\rho V^5}{Pn^2}}$
- η, Efficiency
- n, Revolutions per second, r.p.s.
- Φ, Effective helix angle $= \tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 hp. = 76.04 kg-m/s = 550 ft-lb./sec.
1 metric horsepower = 1.0132 hp.
1 m.p.h. = 0.4470 m.p.s.
1 m.p.s. = 2.2369 m.p.h

1 lb. = 0.4536 kg.
1 kg = 2.2046 lb.
1 mi. = 1,609.35 m = 5,280 ft.
1 m = 3.2808 ft.