NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 518

THE DRAG OF AIRPLANE WHEELS, WHEEL FAIRINGS AND LANDING GEARS
II—NONRETRACTABLE AND PARTLY RETRACTABLE LANDING GEARS

By DAVID BIERMANN and WILLIAM H. HERRNSTEIN, Jr.

1935

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THE DRAG OF AIRPLANE WHEELS, WHEEL FAIRINGS, AND LANDING GEARS
II—NONRETRACTABLE AND PARTLY RETRACTABLE LANDING GEARS

By David Biermann and William H. Herrnstein, Jr.

SUMMARY

This is the second paper giving the results obtained in the N. A. C. A. 20-foot wind tunnel on the drag due to landing gears. The first paper presented the results of tests made with full-scale models of wheels, wheel fairings, and landing gears intended for airplanes of approximately 5,000 pounds weight. The present report gives the results of tests of nonretractable and partly retractable landing gears intended for heavier low-wing monoplanes of the transport and bomber type.

The tests were made on 1/2.8-scale models of gears with a capacity of 16,000 pounds total weight. The landing gears were mounted on a wing of 5-foot chord, 15-foot span, and thickness of 20 percent of the chord. The effect of a radial-engine nacelle mounted in the leading edge of the wing on the drag of the landing gears was also investigated. Propeller tests were made in conjunction with several types of landing gears in order to ascertain the effect of the landing gears on the propeller characteristics.

The tests indicated that, in general, the presence of the engine nacelle did not appreciably affect the drag due to the landing gears. The retractable landing gears were at least one-half retracted into the wing or fairing before the drag became less than that due to the best nonretractable landing gears. Landing gears that were partly retracted into a nacelle near the maximum section or into the wing near the leading edge had a much higher drag than landing gears that were partly retracted farther aft on the wing. The drag due to streamline wheels used on partly retracted landing gears was less than that for low-pressure wheels. Landing gears that were partly or fully retracted into streamline fairings below the wing had only slightly greater drag than those that were partly retracted into the wing or nacelle. The propulsive efficiency was reduced from 1 to 3 percent by the presence of landing gears tested in conjunction with the propeller.

INTRODUCTION

As a result of interest aroused by a previous report on landing gears (reference 1), the program was extended to include tests on landing gears intended for low-wing monoplanes of the transport and bomber types.

Several suitable types of gears that appeared promising in the original program were further investigated. Also, gears intended to partly or fully retract into the wing or into special fairings were tested when in the landing condition as well as in the partly retracted condition. Since airplanes of this type frequently have engine nacelles built into the leading edge of the wing in the same vertical plane as the gear, such a condition was investigated for mutual interference between the nacelle and the gear as well as for the effect of the gear on the aerodynamic characteristics of the propeller.

The chief purpose of the tests was to obtain comparative drag data between the most promising nonretractable gears and the partly retractable gears, and also to obtain quantitative information on the drag of these various types of gears.

APPARATUS AND TESTS

The 20-foot wind tunnel, in which the tests were made, is described in reference 2. The standard apparatus and test methods were used.

The landing gears were tested in the presence of a 15-foot span, 5-foot chord wing mounted in an inverted position. This wing had been used in previous wing-nacelle tests. The tests were run in two parts. In the first part the landing gears were tested in the presence of the wing alone; whereas in the second part an engine nacelle was mounted in the leading edge of the wing (fig. 1). Propeller tests were made in conjunction with several types of landing gears. The wing and nacelle are described in detail in reference 3. The nacelle, which was of the N. A. C. A. cowled type, was located in the position B described in the same reference.

The wing was assumed to be a section of a wing of a 16,000-pound low-wing monoplane scaled down to 1/2.8 size. The model wing thus represented a full-scale wing having a chord of 14 feet and a thickness of 2.8 feet. The model radial engine, which was 20 inches in diameter, therefore represented a full-scale engine of 56 inches diameter.

Only half of each landing gear was tested. Each unit was mounted at the center of the span of the wing

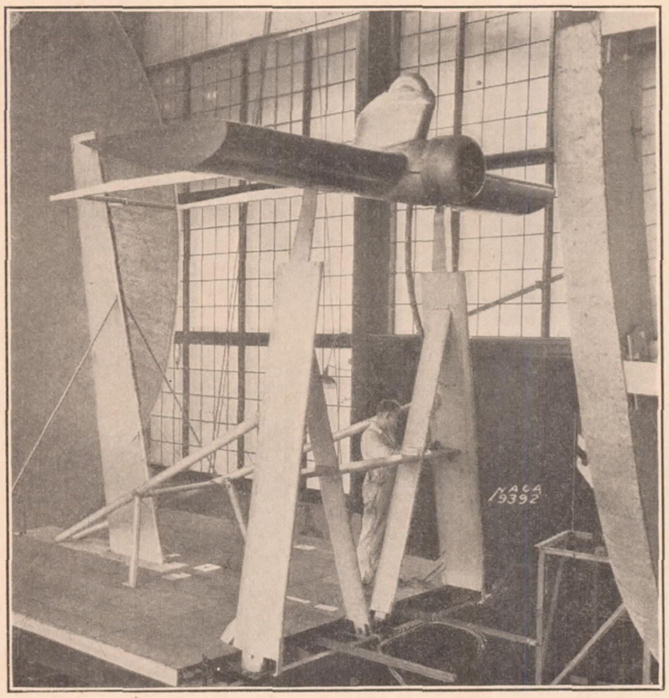
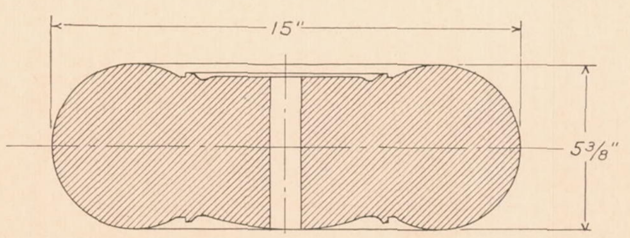
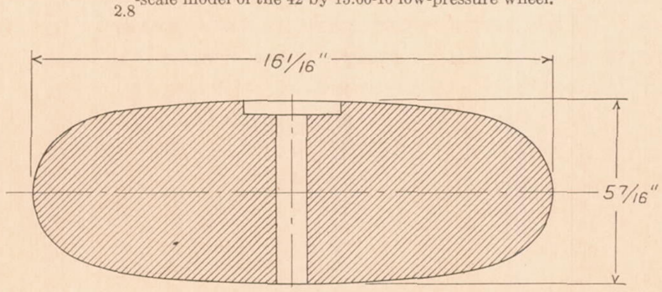


FIGURE 1.—Landing gear A mounted on wing with nacelle.

section near the leading edge. The chordwise location of the wheels when in the landing position was determined from an assumed center-of-gravity location of the complete airplane.



$\frac{1}{2.8}$-scale model of the 42 by 15.00-16 low-pressure wheel.



$\frac{1}{2.8}$-scale model of the 45-inch streamline wheel.

FIGURE 2.—Cross-sectional views of low-pressure and streamline wheels.

A 1/2.8-scale wooden model of a 42 by 15.00–16 low-pressure wheel was used for most of the tests. Some of the tests were also made with a model of a 45-inch streamline wheel. These wheels (fig. 2) have a load-carrying capacity of 8,000 pounds each, according to reference 4.

The principal dimensions of the nonretractable landing gears (A, B, and C) are given in figures 3, 4, and 5.

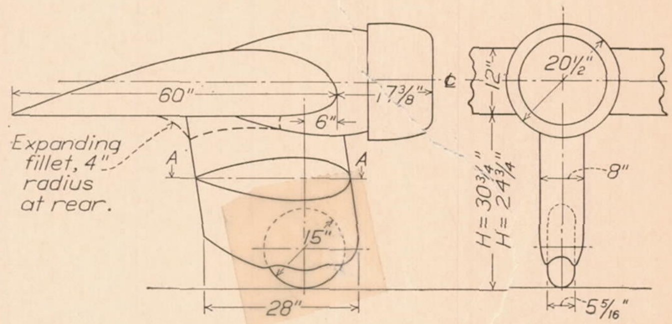


FIGURE 3.—Landing gear A.

These sketches also show the geometric relation between the landing gear, wing, and nacelle (when the nacelle was in place). Two variations of landing-gear height were made, one being 24¾ inches and the other 30¾ inches. These values represent full-scale heights

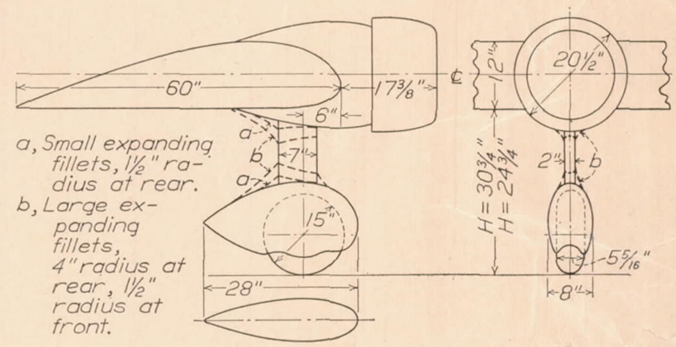


FIGURE 4.—Landing gear B.

of 69⅜ inches and 86 inches, respectively. The sizes of the structural members are believed to be consistent with reasonable design requirements. The shapes and sizes of the fairings and fillets were chosen from the most promising results of previous tests.

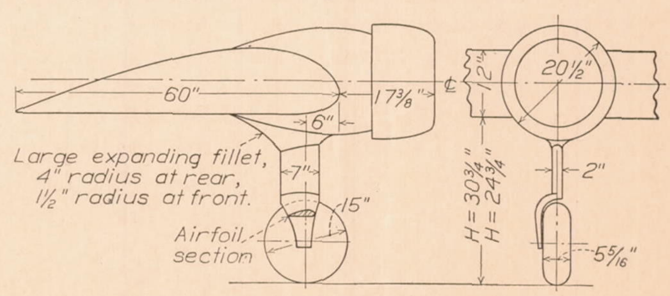


FIGURE 5.—Landing gear C.

A cantilever half-fork landing gear (gear D, fig. 6) was chosen as the basic type to be used for all tests of partly retractable landing gears. The principal dimensions were the same as for the nonretractable types except that none of the members was streamlined.

Two methods of retraction were employed: Retraction by drawing the wheel vertically into the nacelle (when a nacelle was used), and retraction by swinging the wheel rearward into the wing or into special streamline fairings. Dimensions of these fairings are given in figures 7 and 8.

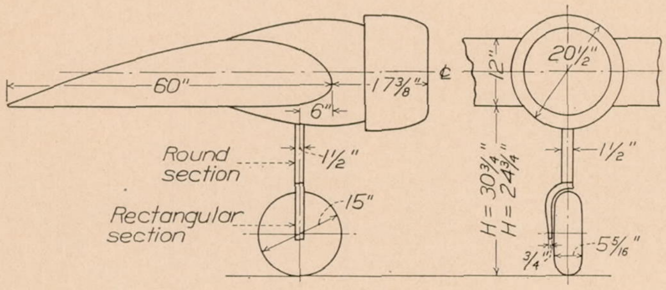


FIGURE 6.—Landing gear D.

In addition to the tests of the complete landing gears, the low-pressure wheel was tested by itself in several chordwise locations on the wing alone and with various degrees of retraction into the wing. Both low-pressure and streamline wheels were tested when yawed various amounts. In these yaw tests the wheels were located 50 percent of the chord from the leading edge and were tested with the tires touching the lower surface of the wing, and also with half of the wheels retracted into the wing.

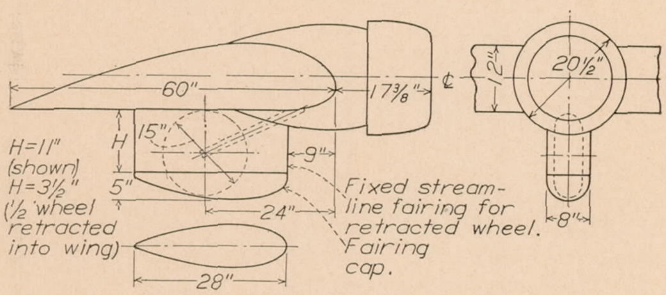


FIGURE 7.—Landing gear D retracted into streamline fairing.

For part of the tests, lift and drag readings of the complete set-up were measured at five air speeds, ranging from 50 to 100 miles per hour, and at six angles of attack ranging from −8° to 4.5°. It was found that for the partly retracted landing gears the lift was not affected by the presence of the landing gear; hence the lift readings were neglected for a part of these tests. The aerodynamic characteristics of the wing and nacelle may be found in reference 3. It should be noted that zero lift of the wing occurs at an angle of attack of about −7.5° and that the lift coefficient of the wing at 0° angle of attack is 0.366.

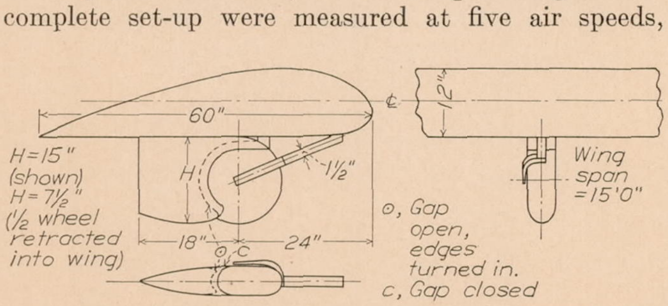


FIGURE 8.—Landing gear D partly retracted into streamline fairing.

The measured lift was reduced to the usual coefficient, C_L. The drag due to the landing gears in the presence of the wing, or the wing and nacelle, was assumed to be equal to the drag of the complete set-up with the landing gear in place minus the drag of the wing alone, or the wing plus nacelle as the case might be. The drag difference, in pounds, at 100 miles per hour was taken at constant values of lift coefficient of the wing. The final drag results due to the model landing gears are plotted against lift coefficient.

Since the model was 1/2.8 full size, the drag of both halves of the full-scale landing gears, neglecting scale effect, would be:

$$2.8^2 \times 2 \times \left(\frac{V}{100}\right)^2 \times D, \text{ or } 15.68 \left(\frac{V}{100}\right)^2 \times D$$

where

V is velocity of full-scale airplane, miles per hour.
D is the drag of model landing gear, pounds.

When applying the results to similar landing gears with dimensions differing from those of the gears investigated, reasonably close approximations may be made by using the ratios of the projected areas of the landing gears for the characteristic areas. Some judgment should be exercised, however, in applying the results to landing gears of different size and shape, especially to those used on high-speed airplanes.

The propeller characteristics are reduced to the usual coefficients:

$$C_T = \frac{(T - \Delta D)}{\rho n^2 D^4} \qquad C_P = \frac{P}{\rho n^3 D^5}$$

where

T is thrust of propeller (tension in shaft).
ΔD, increase in drag due to action of propeller.
n, revolutions per unit time.
D, propeller diameter.
P, motor power.

and

η, propulsive efficiency.

$$= \frac{C_T}{C_P} \frac{V}{nD}$$

The results obtained in tests of landing gears and wheels made in the presence of the wing without nacelle are presented in figures 9 to 16, inclusive: Nonretractable types in figures 9, 10, and 11; retractable types in figures 11 to 14, inclusive; of wheels in various locations in figure 15; and wheels with different degrees of yaw in figure 16.

The results obtained from tests of landing gears and wheels made in the presence of the wing and nacelle are presented in figures 17 to 25, inclusive: Nonretractable landing gears in figures 17, 18, and 19; retractable landing gears in figures 19 to 22, inclusive;

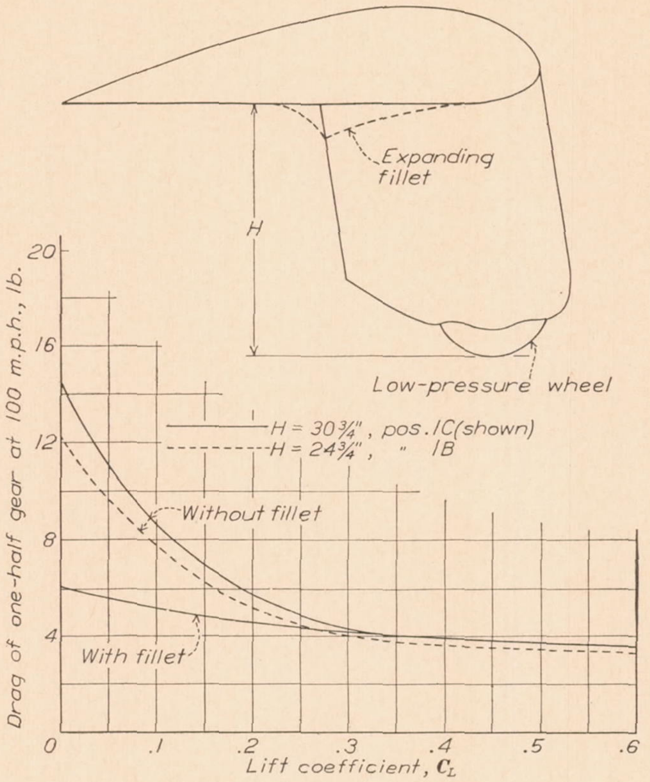


FIGURE 9.—Drag of landing gear A in presence of wing.

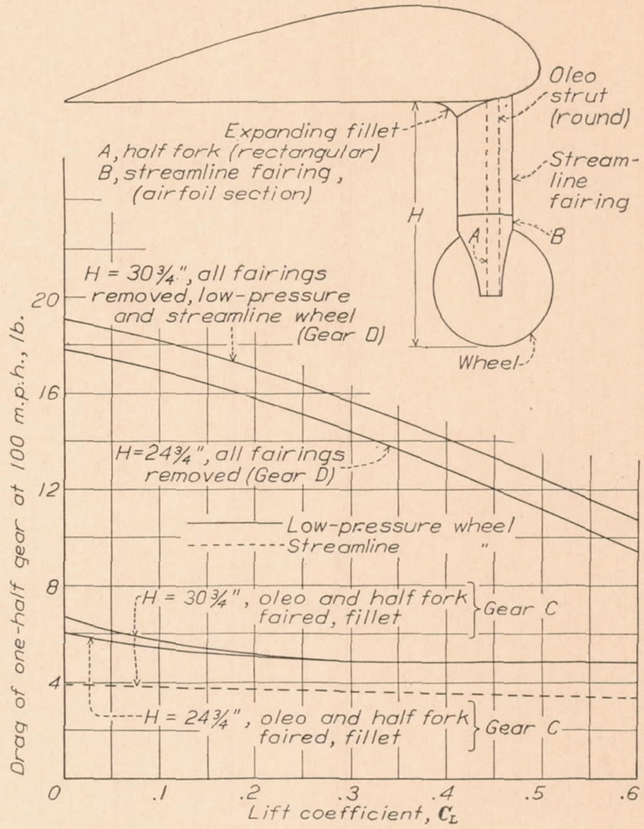


FIGURE 11.—Drag of landing gears C and D in presence of wing.

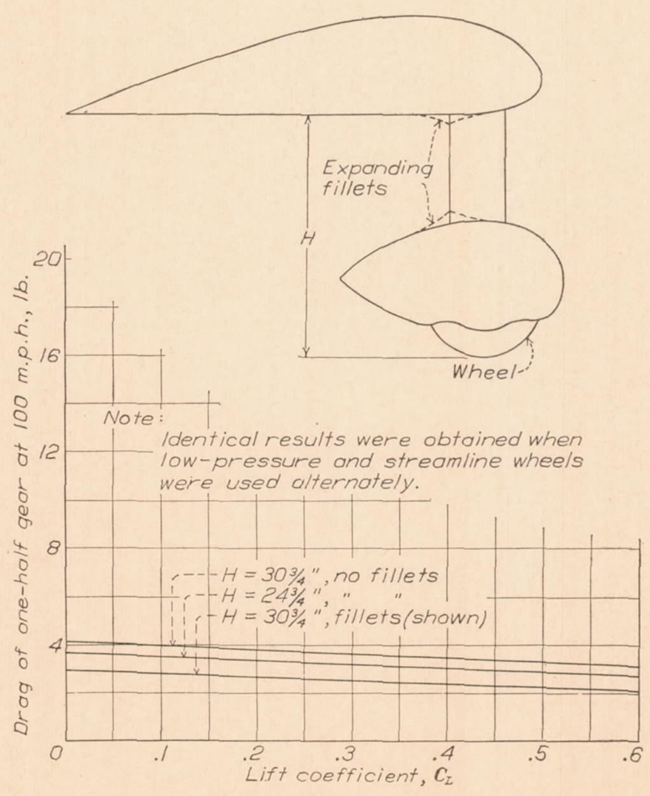


FIGURE 10.—Drag of landing gear B in presence of wing.

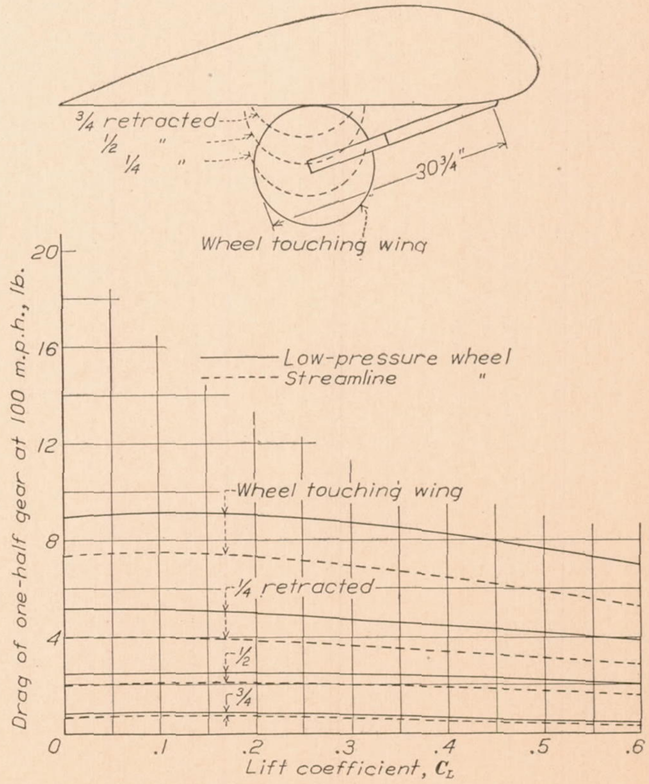


FIGURE 12.—Drag of landing gear D retracted by various amounts into wing.

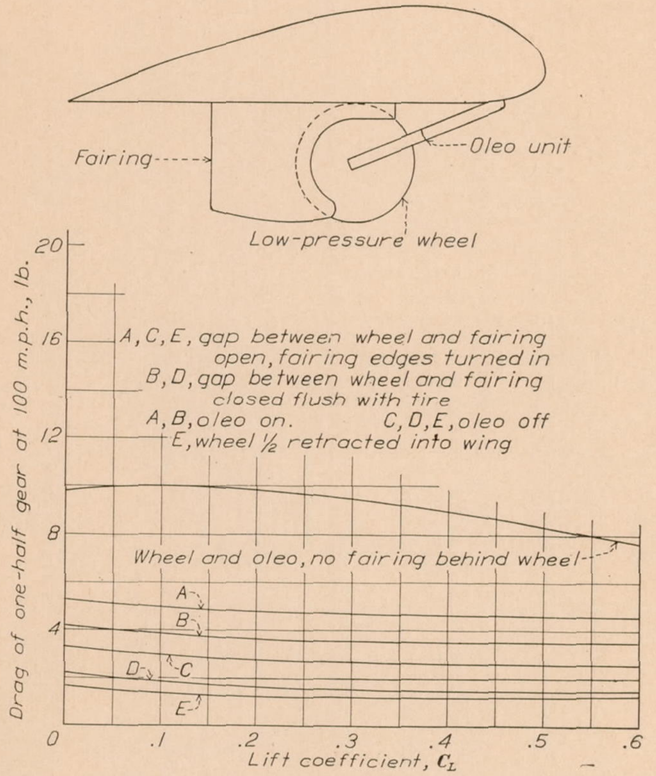


FIGURE 13.—Drag of landing gear D partly retracted into streamline fairing in presence of wing.

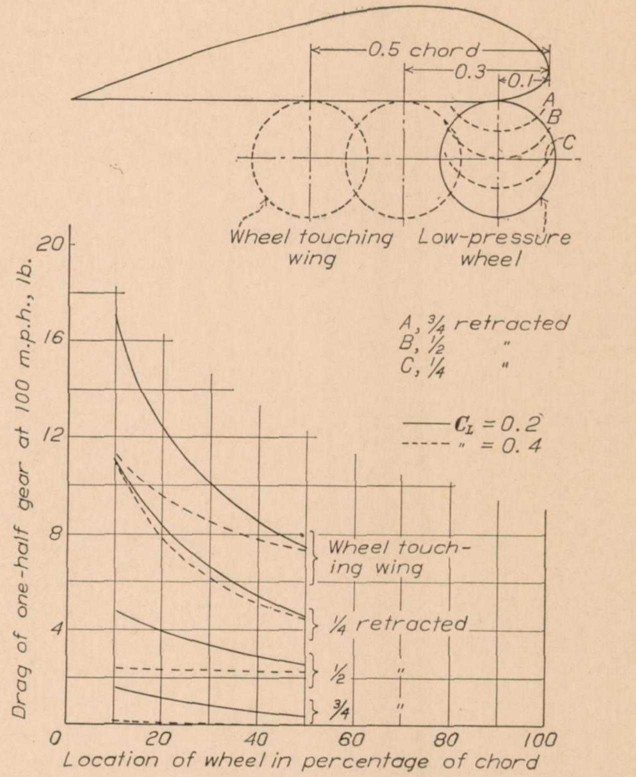


FIGURE 15.—Drag of low-pressure wheel at various chordwise locations and with various degrees of retraction into wing.

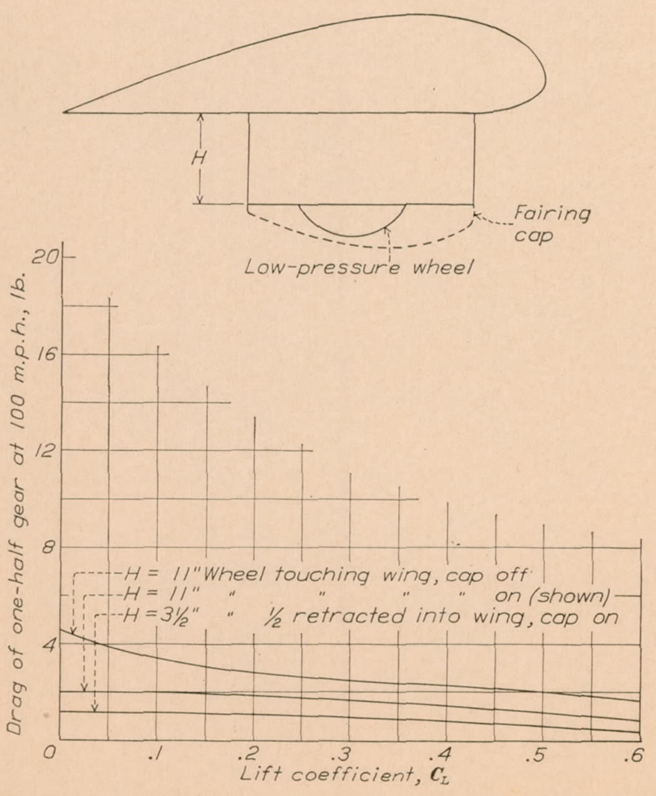


FIGURE 14.—Drag of landing gear D retracted into streamline fairing in presence of wing.

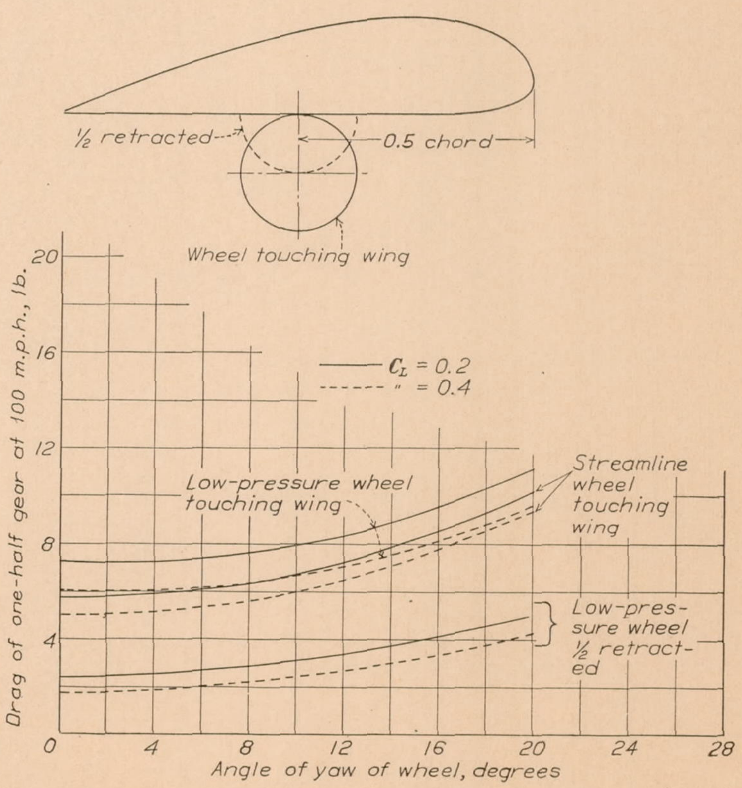


FIGURE 16.—Drag of low-pressure and streamline wheels in yaw in presence of wing.

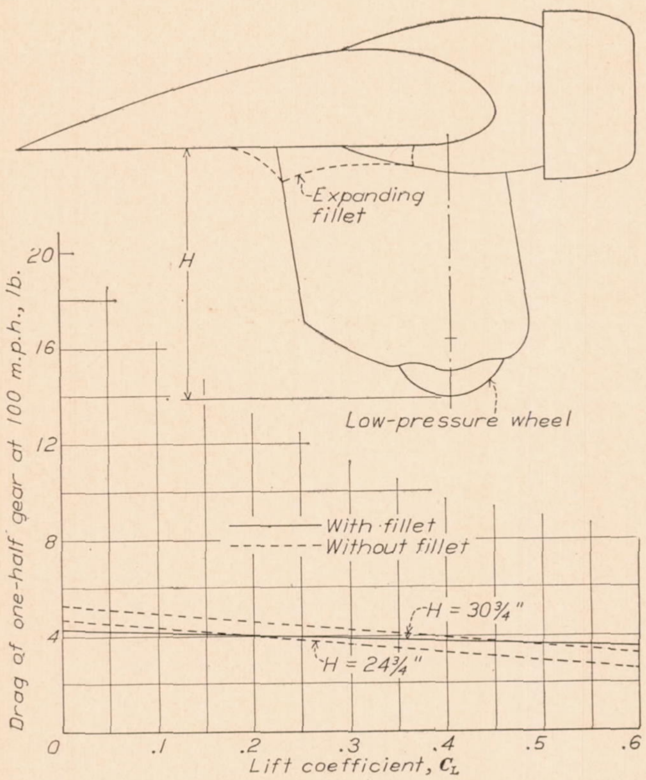


FIGURE 17.—Drag of landing gear A in presence of wing and nacelle.

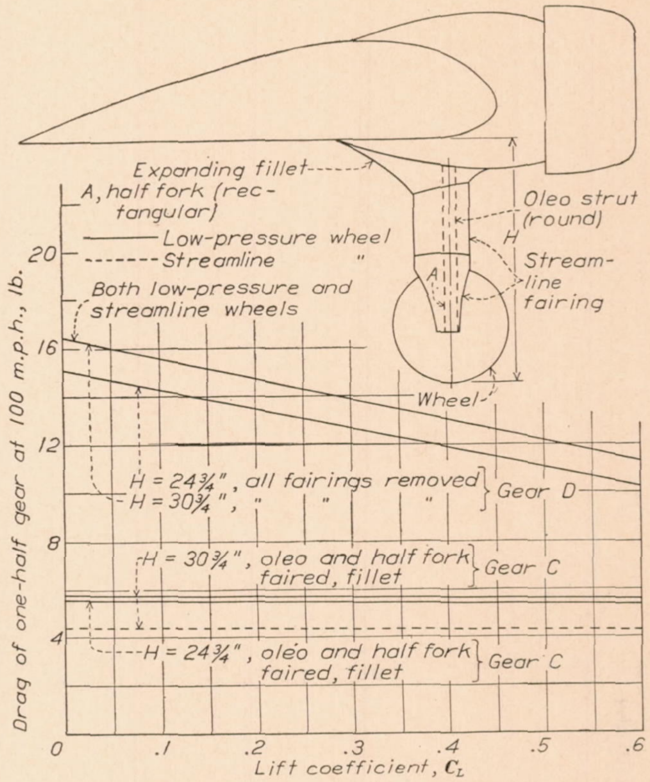


FIGURE 19.—Drag of landing gears C and D in presence of wing and nacelle.

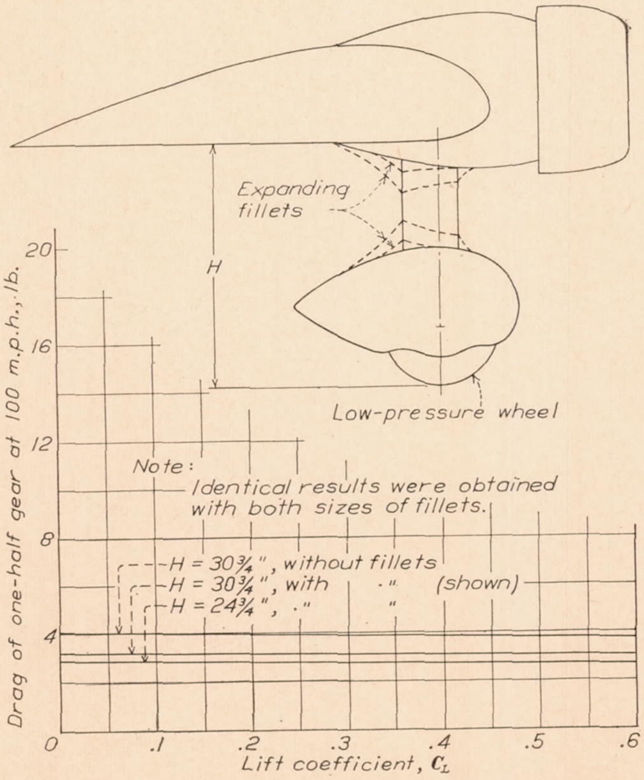


FIGURE 18.—Drag of landing gear B in presence of wing and nacelle.

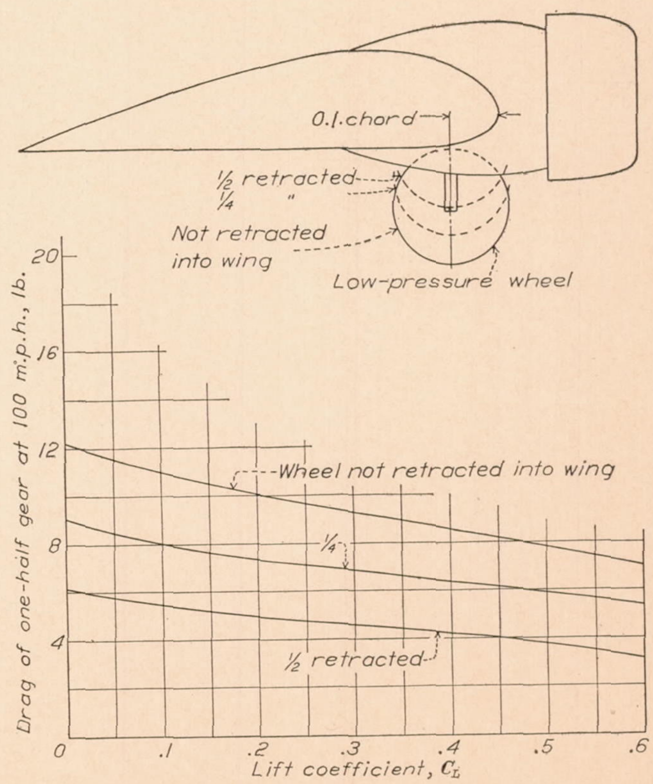


FIGURE 20.—Drag of landing gear D retracted vertically by various amounts into nacelle.

wheels in yaw, in figure 23; and the results of propeller tests made in conjunction with several different landing gears in figures 24 and 25.

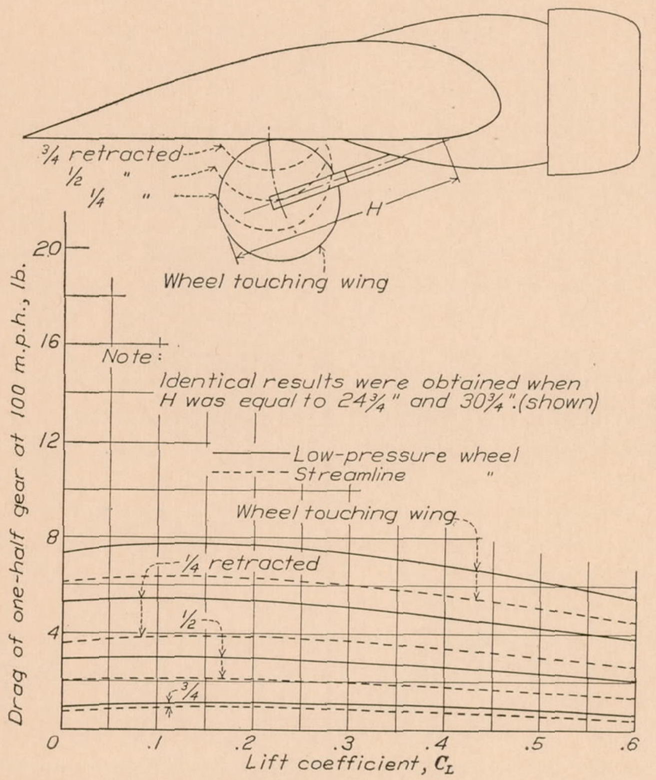


FIGURE 21.—Drag of landing gear D retracted various amounts into wing in presence of nacelle.

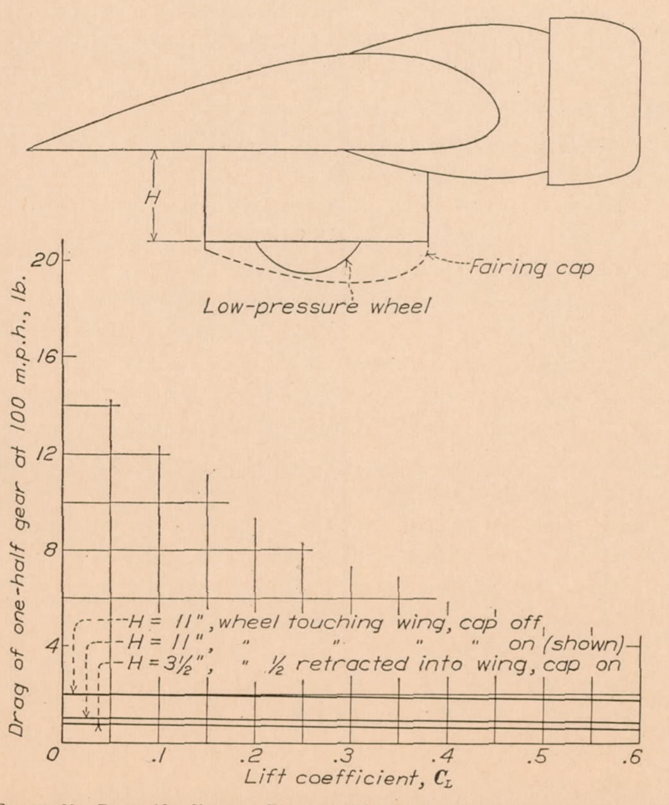


FIGURE 22.—Drag of landing gear D retracted into streamline fairing in presence of wing and nacelle.

ACCURACY

The faired drag curves are believed to be accurate to within one-half pound. For the low-drag landing gears this represents a relatively high percentage of the landing-gear drag. However, since a fairly large

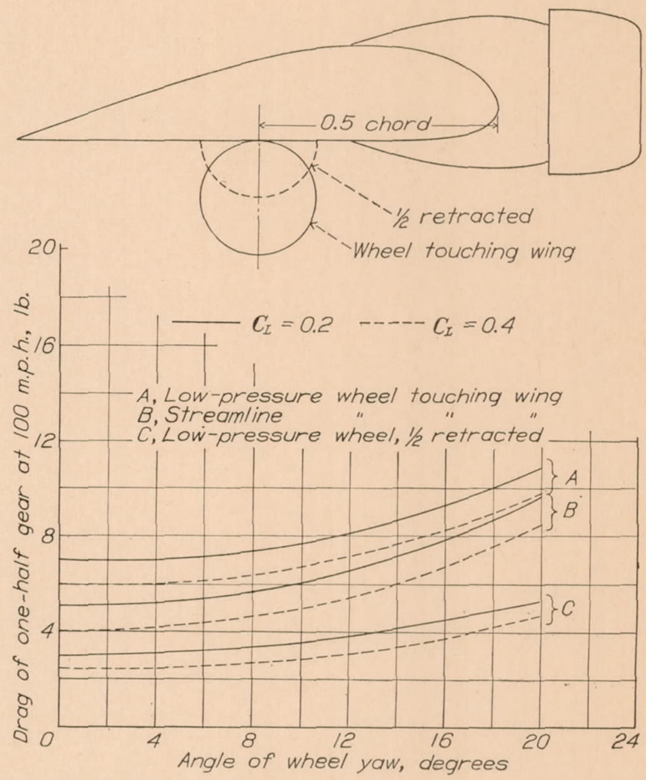


FIGURE 23.—Drag of low-pressure and streamline wheels in yaw in presence of wing and nacelle.

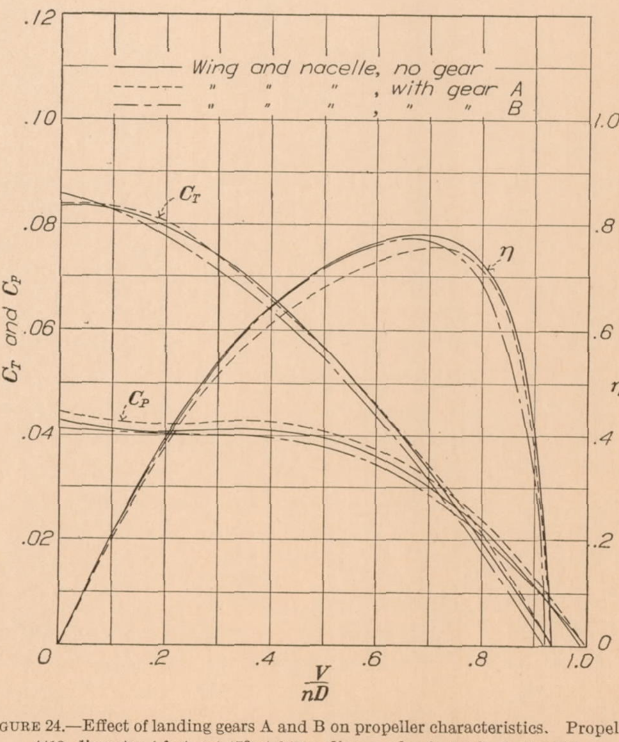


FIGURE 24.—Effect of landing gears A and B on propeller characteristics. Propeller 4412, diameter 4 feet, set 17° at 0.75 radius; angle of attack of wing, 0°.

number of tests were made on landing gears with only slight changes, it was possible to improve the accuracy by fairing at one time a series of curves for one type of landing gear. The results are considered sufficiently accurate for comparative purposes and should give fairly close approximations when applied to full-scale airplanes. The faired lift curves are considered correct within ±1 percent at 0° angle of attack.

The thrust and power coefficients are thought to be correct within ±1 percent over the greater portion of the curves, while the propulsive efficiency is believed to be correct within ±2 percent.

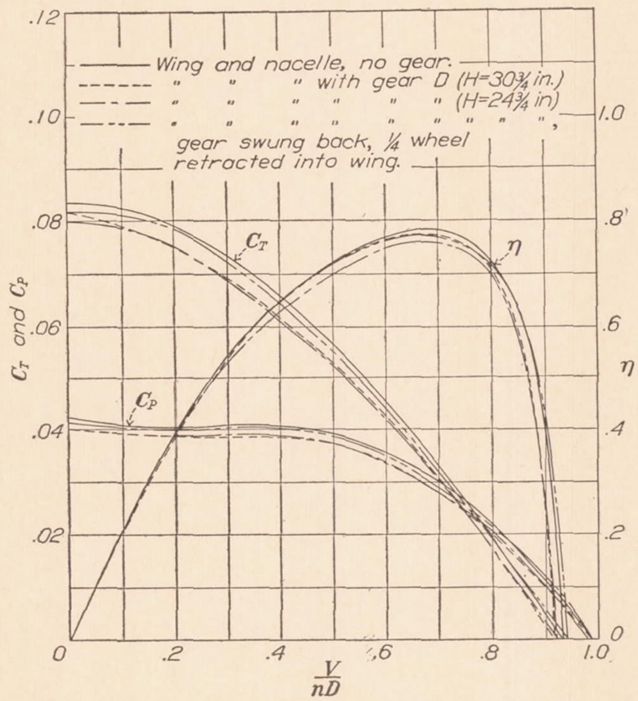


FIGURE 25.—Effect of landing gear D on propeller characteristics. Propeller 4412, diameter 4 feet, set 17° at 0.75 radius; angle of attack of wing, 0°.

DISCUSSION

LANDING GEARS AND WHEELS MOUNTED ON WING WITHOUT NACELLE

Nonretractable types.—Figure 9 presents the results from tests of landing gear A. At low values of lift coefficient the drag due to the landing gear was reduced considerably by the presence of an expanding fillet. The term "expanding" refers to the fillet radius and means that it increases progressively in the downstream direction. In this instance the fillet started with nearly zero radius at the maximum section of the landing-gear fairing and increased to about 4 inches at the trailing edge of the fairing. The drag of the landing gear was not critical to changes in lift coefficient when a fillet was present.

The results from tests of landing gear B are given in figure 10. It should be noted that this landing gear had the lowest drag of any nonretractable gear tested. Even though the oleo strut was small in comparison to the fairing used on landing gear A, the presence of expanding fillets materially reduced the drag of the landing gear.

The results from tests of landing gear C, which was a half-fork type equipped with both low-pressure and streamline wheels, are given in figure 11. For this type of landing gear the drag was considerably lower when streamline wheels were used. The presence of the airfoil section adjacent to the wheel was thought to be an important factor in obtaining the low drag.

Partly retractable types.—Figure 11 also shows the results from tests of landing gear D. As may be seen, the only difference between landing gears C and D was the lack of the streamline fairing on the fork and oleo strut of landing gear D. At a lift coefficient of 0.2 the drag was increased from 5 to 17 pounds for the 30¾-inch landing gear by removing the strut and fork fairings. It is noteworthy that the slopes of these curves are much greater than for those of landing gear C. The probable reason for this increase is the increasingly disturbing effect of the oleo strut on the flow over the wing with decreasing values of lift coefficient. The same effect was previously noted in the case without fillet on landing gear A.

Values of drag due to landing gear D when partly retracted into the wing by various amounts are shown in figure 12 for both streamline and low-pressure wheels. The drag of the landing gear equipped with streamline wheels ranges from 15 to 20 percent less than for low-pressure wheels, regardless of the amount the landing gear is retracted into the wing. Although the landing-gear drag (with low-pressure wheels) is reduced considerably by folding the wheel against the wing, the wheel must be retracted at least one-fourth into the wing before the drag becomes less than that for landing gear C and one-half before the drag becomes less than for landing gear B.

From structural considerations it may be undesirable to retract the landing gear either fully or partly into the wing. Figure 13 illustrates the results from tests on landing gear D partly retracted into a streamline fairing mounted on the lower surface of the wing. The drag of the landing gear when folded against the wing was reduced about 50 percent by the presence of a streamline fairing behind the tire (gap open between tire and fairing, see fig. 8) and was reduced an additional 12 percent by closing the gap between the wheel and the fairing. Removing the oleo strut and fork reduced the drag still further by about 20 percent.

With the landing gear one-half retracted into the wing the presence of a fairing (gap open) behind the portion of the wheel that remained in the air stream reduced the drag approximately 50 percent. (See figs. 12 and 13 for comparison.)

Still greater reductions in drag may be gained by completely retracting the landing gear into a streamline fairing (fig. 14). The landing-gear fairing, with the cap on, had less than half the drag of the landing gear partly retracted into the fairing previously discussed. Removal of the fairing cap, however, increased the drag about 55 percent at a lift coefficient of 0.2.

Wheels.—The results from tests of wheels at various chordwise locations and with various degrees of retraction into the wing are given in figure 15. At low values of the lift coefficient (0.2) the drag due to the wheel increased rapidly as the wheel was moved toward the leading edge. For higher values of the lift coefficient (0.4) the wheel location was less critical, with the exception of the wheel one-fourth retracted. For any chordwise location the drag due to the wheel reduced rapidly with retraction.

Figure 16 shows the results from tests of both low-pressure and streamline wheels in yaw. At a lift coefficient of 0.2 the drag due to the low-pressure wheel when touching the wing at the 50 percent chord point was increased about 10 percent due to 10° yaw and about 55 percent due to 20° yaw. Although the streamline wheel had less drag, the increased drag due to yaw amounted to about 17 percent for 10° yaw and about 75 percent for 20° yaw. With the low-pressure wheel one-half retracted into the wing the increased drag due to yaw amounted to about 30 percent for 10° yaw and over 100 percent for 20° yaw.

LANDING GEARS AND WHEELS MOUNTED ON WING WITH NACELLE

These tests were almost identical with the tests of landing gears and wheels mounted on the wing without nacelle and, in general, the results are about the same. There are, however, a few interesting points.

Nonretractable types.—Expanding fillets on landing gear A (fig. 17) were not so effective at low values of the lift coefficient as they were without the nacelle. Evidently the nacelle had the effect of preventing separation of flow at the intersection of gear and wing for these negative angles of attack.

Increasing the size of the expanding fillets used on landing gear B (fig. 18) did not affect the drag, even though the small fillets materially reduced the drag.

The streamline wheel, as well as the low-pressure wheel, was used both on landing gears C and D (fig. 19). The drag due to landing gear C was materially less with the streamline wheel than with the low-pressure wheel. When the streamline fairings had been removed from the half-fork and oleo strut (landing gear D), there was no apparent advantage, however, in the streamline wheel.

Partly retracted types.—It appears from figure 20 that partly retracting landing gear D vertically into the nacelle at its maximum cross section is undesirable with respect to drag. At a lift coefficient of 0.2 the drag due to the landing gear when half the wheel was retracted into the wing (leaving only slightly more than the tire protruding out of the nacelle) was greater than the drag due to landing gears A and B and almost as high as for landing gear C. The drag of landing gear D when partly retracted by this method was considerably higher than when retracted by swinging the wheel back into the wing (fig. 21).

The drag due to landing gear D enclosed in a streamline fairing (fig. 22) was somewhat less with the nacelle in place than when tested on the wing without nacelle (fig. 14).

Wheels.—The results from tests of wheels in yaw measured in the presence of the wing and nacelle (fig. 23) are almost identical with the results from tests of wheels in presence of the wing without the nacelle.

Propeller characteristics.—The propeller characteristics measured in the presence of the wing and nacelle alone and also in the presence of the nonretractable landing gears A and B are given in figure 24. The peak propulsive efficiency was reduced about 2.5 percent by the presence of landing gear A, the reduction being manifested by an increased power coefficient. The propeller was less affected by the presence of landing gear B, the propulsive efficiency being reduced only about 1 percent.

The propeller characteristics measured in the presence of landing gear D in the landing position and also one-fourth retracted into the wing are given in figure 25. Both the thrust and power curves are somewhat lower than those for the wing and nacelle alone throughout the range for both attitudes of the landing gear. The peak propulsive efficiency, however, was reduced only about 1 percent for the landing gear in the partly retracted position as well as for the landing gear of 30¾-inch height in the landing position. For the landing gear of 24¾-inch height in the landing position the propulsive efficiency was reduced about 2 percent for the climbing and high-speed range of V/nD.

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:

1. In general, the presence of the engine nacelle did not appreciably affect the drag due to the landing gears.

2. The retractable landing gears were at least one-half retracted into the wing or a fairing before the drag became less than that due to the best nonretractable landing gears.

3. Landing gears that were partly retracted into a nacelle near the maximum section or partly retracted into the wing near the leading edge had a much higher drag than landing gears that were partly retracted farther aft on the wing.

4. Streamline wheels used on retractable landing gears had less drag than low-pressure wheels when the landing gear was partly retracted into the wing.

5. Landing gears that were partly or fully retracted into streamline fairings below the wing had, in general, only slightly greater drag than landing gears that were partly retracted into the wing or nacelle.

6. The peak propulsive efficiency was reduced from 1 to 3 percent by the presence of the landing gears tested in conjunction with the propeller.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY FIELD, VA., *June 21, 1934*.

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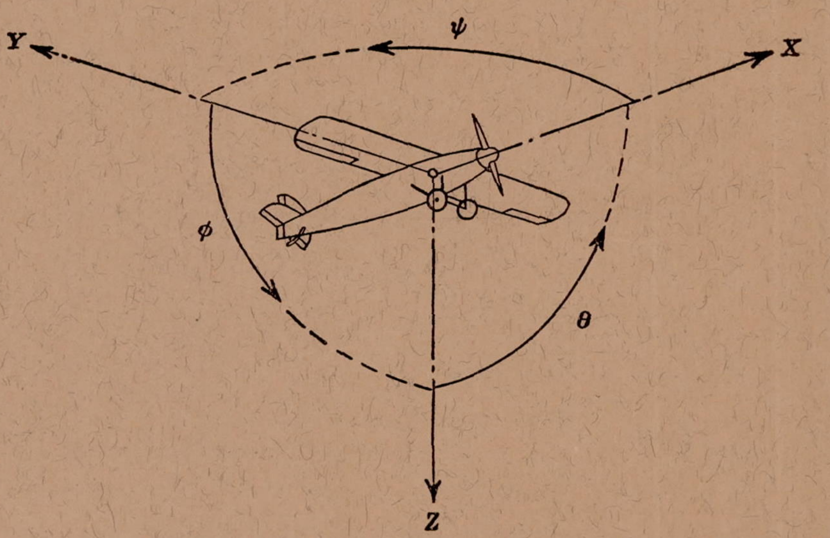

Positive directions of axes and angles (forces and moments) are shown by arrows

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

$C_l = \frac{L}{qbS}$ (rolling) $C_m = \frac{M}{qcS}$ (pitching) $C_n = \frac{N}{qbS}$ (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 $= \sqrt[5]{\frac{\rho V^5}{P n^2}}$
- 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 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.