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SPECIAL REPORT #63

NOTES ON FACTORS AFFECTING GEOMETRICAL ARRANGEMENT
OF TRICYCLE-TYPE LANDING GEARS

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SUMMARY

In this paper are discussed the effects of the geometrical arrangement of tricycle landing gears on various characteristics of an airplane equipped with such a landing gear. The characteristics discussed include directional stability, overturning tendencies, steering and ground handling, shimmy, take-off, and porpoising. The conclusions are summarized in a table.

INTRODUCTION

The tricycle landing gear has recently been receiving considerable attention because of its possibilities for greatly improving the stability and handling characteristics of the airplane on the ground and for increasing the ease with which landings may be made. (See reference 1.) This type of landing gear has two fixed wheels (usually equipped with brakes) behind the center of gravity and a stable castoring wheel considerably ahead, which may or may not be steerable.

An airplane equipped with the tricycle landing gear will have the following properties not possessed by one with the conventional gear:

1. The airplane will be directionally stable when taxiing on the ground and will not have a propensity to ground looping. This freedom from ground looping permits cross-wind landings with side drift to be made, and the airplane becomes very maneuverable on the ground.

2. The brakes may be fully applied at contact with the ground and during the ground run without danger of nosing over, which considerably decreases the landing distance.

3. Landing and take-off characteristics are somewhat different than for airplanes with the conventional gear because the angle of attack of the wing is small when the three wheels of the tricycle gear are all on the ground.

4. Shimmy of the front wheel is more likely to occur than for the conventional tail wheel, and it is more difficult to damp out the front wheel shimmy by the usual spindle damping method because of the greater wheel size.

This report contains theoretical discussions of some of the problems raised by these differences and includes qualitative effects of different locations of the center of gravity of the airplane with respect to the tricycle landing gear.

DEFINITIONS

A sketch of a tricycle landing gear is given in figure 1 in which the various factors involved are indicated.

Caster angle: The angle between the center line of the front wheel spindle and a perpendicular to the reference line of the airplane. Positive when the lower end of the spindle is forward of the upper end.

Caster length: The distance measured perpendicular to the spindle axis from the center of the front tire contact area to the spindle axis. Positive to the rear of the spindle axis.

Offset: The distance of the front wheel axis relative to the front wheel spindle axis. Positive to the rear of the spindle axis.

Rolling radius: The distance from the wheel axle to the ground under a given loading condition.

Longitudinal wheel base: The distance measured in a horizontal plane between the front wheel axle and a vertical plane containing the rear wheel axles, with nose wheel on ground.

Lateral wheel base: The distance between center lines of the rear wheel tires when under load on the ground.

The definitions of h , h_1 , l , l_1 , l_2 , l_3 , L , d , and r are clear from figure 1.

W , weight of airplane.

m , mass of airplane.

k_z , radius of gyration about vertical axis through c.g.

μ , coefficient of friction between the tires and ground, either rolling or sliding.

The airplane used as an example throughout this paper, the W-1A, is described in reference 1. The W-1A weighs 1,200 pounds and the other values, in feet, are as follows:

h	=	4.0
r	=	0.5
l_1	=	0.78
l_2	=	7.68
l_3	=	9.0
l	=	8.46
L	=	0.23
k_z	=	4.75 (estimated)

The values of μ were obtained from reference 2.

DISCUSSION OF VARIOUS CHARACTERISTICS OF THE TRICYCLE LANDING GEAR

Directional stability.— One of the most desirable features of the tricycle landing gear is its directional stability, which removes from the pilot a large amount of the skill required to guide the airplane on a straight course while on the ground. An airplane equipped with a tricycle landing gear will not only run straight of its own accord

but will recover from any directional disturbances that might be supplied by bumps, cross-wind landings, etc. The following calculations indicate the speed of this recovery.

It is assumed that no side force is supplied by the nose wheel. This assumption is approximately true if there is not too much friction in the front wheel spindle, if the caster angle is not too large, and if the front wheel is free to caster.

Suppose an airplane to touch the ground with a direction of motion at an angle ψ_0 (radians) with the direction of heading. A side force Y will be applied to the rear wheels (see fig. 2) as soon as they strike the ground. This side force will give rise to a lateral acceleration $\dot{v} = Y/m$ and to a couple Yl_1 about the c.g. This couple gives rise to an angular acceleration $\ddot{\psi} = Yl_1/mk_z^2$. There also arises a couple about the longitudinal axis due to the application of the force Y at a distance $(h+r)$ below the c.g. This effect results in an additional force on the inside tire and a decrease in force on the outside tire. These force increments just balance the above-mentioned torque about the longitudinal axis. Let the force increment on each wheel be x , then

$$Y(h+r) = 2 \left(x \frac{l_3}{2} \right)$$

or

$$x = Y \frac{h+r}{l_3} \quad (\text{per wheel})$$

If the tires roll with a coefficient of rolling friction μ , the forces x will result in a couple about the Z axis

$$2 \left(\mu x \frac{l_3}{2} \right) = \mu x l_3 = Y(h+r)\mu$$

Thus, the total angular acceleration will be

$$\ddot{\psi} = \frac{Y}{mk_z^2} [l_1 + (h+r)\mu]$$

If the rear wheels are not to skid sidewise, then the airplane must move in the direction of heading which gives it a velocity $-v = U_0 \psi$ perpendicular to the direction

of motion. Combining these equations so as to eliminate v and Y

$$mk_z^2 \ddot{\psi} = - [l_1 + (h+r)\mu] m U_0 \dot{\psi}$$

The solution of most interest is

$$\psi = \psi_0 e^{-\frac{[l_1 + (h+r)\mu] U_0}{k_z^2} t} \quad (1)$$

This equation indicates that any directional disturbance such as a bump or a landing with side drift will be reduced to $\frac{1}{2.718}$ times its original magnitude in a distance $\frac{k_z^2}{[l_1 + (h+r)\mu]}$ feet. For the W-1A with $\mu = 0.05$ this distance is 22.5 feet. It is, of course, desirable to make the response rapid and it was found that the response of this airplane was satisfactory.

It should be pointed out that these calculations show that a tricycle landing gear will always be stable since the exponent in equation (1) is always negative for the c.g. ahead of the rear wheels. It has been found that all of the tricycle landing gears constructed thus far have been stable at all normal taxiing speeds even in the presence of a strong cross wind.

The aerodynamic effect of the fin, which has been neglected, should ordinarily make the airplane somewhat more stable than is indicated by these calculations.

Overturning tendencies of tricycle landing gears.-

It appears desirable to develop a criterion for a tricycle landing gear so that it will skid rather than nose over in all contacts with level ground.

Consider the triangle formed by the three wheels as apexes. (See fig. 3.) Let the resultant of all the accelerations acting at the c.g. be represented by an acceleration vector extending in the proper direction out from the c.g. If this resultant vector intersects the ground inside the triangle, then the airplane will not overturn; if it intersects the ground outside the triangle, then it will overturn.

$$* \psi_1 = \psi_0 e^{-\lambda t_1}; \psi_2 = \psi_0 e^{-\lambda t_2}; e = \frac{\psi_1}{\psi_2} = e^{(-\lambda t_1 + \lambda t_2)}; t_2 - t_1 = \frac{1}{\lambda}$$

The largest possible magnitude of the horizontal acceleration vector will be μW ; (the presence of vertical accelerations greater than g will not affect the final result) hence, the greatest distance of the intersection of the resultant vector with the ground from the c.g. will be $\mu (h + r)$. Clearly this acceleration will be most likely to nose the airplane over when it is perpendicular to one side of the triangle. The condition for nosing over will be

$$\begin{aligned} \mu (h + r) &\geq l_2 \sin \theta \quad \checkmark \quad (\text{see fig. 3}) \\ &\geq l_2 \sin \tan^{-1} \frac{l_3}{2l} \quad \checkmark \end{aligned}$$

Note: Friction on fore wheelability nose wheel may be less.

Thus the W-1A airplane with

$$(h + r) = 4.5 \text{ ft.}, \quad l_2 = 7.68 \text{ ft.},$$

$$l = 8.46 \text{ ft.}, \quad l_3 = 9.0 \text{ ft.}$$

would nose over for $\mu \geq 0.8$, if the tires were slipping at exactly the correct angle. The propeller thrust might make the airplane somewhat more likely to tip over but probably would not be applied simultaneously with the brakes.

An airplane with a tricycle-type landing gear will overturn backward when the c.g. is behind the axle of the main wheels. Thus the largest angle to which the airplane can be tilted backward and still return is approximately l_1/h radians. This angle amounted to about 10° for the W-1A airplane.

Steering and ground handling. - Some difficulty is encountered in maneuvering tricycle landing gears in soft ground at low speeds, especially in the presence of much caster angle, in which case the wheel is unstable at very low speeds. It seems from the information available that this difficulty could be overcome by either of the following methods:

First, if the front wheel is made steerable through small angles at low speeds it will probably show much more ability to get out of holes, etc., and the pilot will always be able to prevent the wheel from assuming a crossed position. Steering, however, introduces difficulties. The wheel is more likely to shimmy than before and it is

practically necessary to have the wheel disengaged from the steering control in landing and taking off so that the directional stability of the landing gear will not be impaired.

Second, if caster angle is not used the wheel will not tend to tip over sidewise and it will be easier to maneuver the airplane on the ground at low forward speeds. It is therefore advisable that all of the caster length used be obtained by fork offset. In any case, there should be stops on the front wheel spindle so that it cannot rotate through angles greater than those necessary for ground maneuvering.

The steering mechanism must overcome two torques: one due to spindle friction, which may be used to combat shimmy; and the other due to the natural stability of the landing gear when in motion (assuming no caster angle). An approximate calculation of the torque in the latter case will be given. Let R be the radius of curvature of the turn under consideration. Then the centrifugal force on the airplane is mV_0^2/R . This load will be divided between the front and rear wheels in the same way that the weight is divided, i.e., the side load on the front wheel will be $\frac{mV^2}{R} \cdot \frac{l_1}{l}$ and the steering torque that must be overcome is approximately equal to this force times the caster length of the wheel, or $\frac{mV^2}{R} \cdot \frac{l_1}{l} L$. For the W-1A, with $v = 50$ feet per second, substituting in the formula

$$\text{Torque} = \frac{1970}{R} \text{ foot-pounds}$$

Thus, for a radius of turn of 100 feet the torque would be 19.7 foot-pounds.

Shimmy of front wheel.— A theoretical analysis of the dynamic stability of castering wheels is being made by the N.A.C.A. and will be published later. The analysis has been verified experimentally on small models and is still to be checked full-scale. It indicates that in most cases the following things should be helpful in avoiding shimmy. The items are listed in the order of their effectiveness.

1. Friction or hydraulic damping in the front wheel spindle. As much friction should be used in the spindle

as will not interfere with ground maneuverability. If solid friction is used, it will be necessary to use some device to have the wheel properly centered on contact with the ground.

2. Use of high-pressure tires; Increased tire pressure.

3. Rear wheels located close to the c.g.

4. Small caster length.

5. Reduction of any spring-restoring forces that might tend to keep the wheel straight to the amount necessary to keep the wheel straight when it is not in contact with the ground.

Take-off.— Take-off with a tricycle landing gear differs from that with a conventional landing gear in that when all the wheels are resting on the ground the angle of attack of the wing is usually small. Thus in the early stages of the take-off run when it is difficult to control the angle of attack, the lift and the induced drag are smaller with the tricycle-type gear than with the conventional gear.

If the condition of the field is such that it is more efficient to have the weight of the airplane supported by the ground than by the air, then this represents a gain. But when take-off is most difficult, on a soft or an uneven field, this characteristic of tricycle landing gears will make it slightly more difficult. In the latter case it would appear advisable to lift the front wheel as soon as possible, thus increasing the angle of attack.

The moments which tend to keep the front wheel down are the moment of the weight of the airplane about the rear axle Wl_1 and the moment of the propeller thrust about the rear axle $T(h_1 + h)$. The moments that tend to lift the nose are the reaction of the airplane to forward acceleration \dot{u} , which has a magnitude $m\dot{u}h$, and the moment supplied by the aerodynamic drag M_A . The difference between these two groups of moments

$$Wl_1 + T(h_1 + h) - m\dot{u}h - M_A$$

must be supplied by the elevator. Hence it will be seen

that in order to reduce the moment required from the elevator and hence reduce the speed at which the nose can be raised, it will be desirable to reduce l_1 , to increase h , and especially to keep the thrust axis low. *(See with 1/4 page)*

Since these considerations apply only at the low speeds at which there is not adequate elevator control, i.e., at speeds considerably below minimum flying speed, the effect on the total take-off run will be small.

Porpoising.- It has been found in one case of an airplane equipped with a tricycle landing gear that, when $\frac{l_1}{l} \leq 0.08$, a slow oscillation in pitch, called "porpoising," occurred. This oscillation has not been encountered with more forward positions of the c.g.

Design loads.- Design loads for tricycle landing gears are being investigated both experimentally and theoretically by the N.A.C.A. and the results are to be published later. It appears that, if the tricycle gear is to be used in a manner similar to that of the conventional gear, then the main wheel structure need be no stronger for equal safety. However, if full advantage is to be taken of the capabilities of the tricycle gear, then the main wheel structure should be stronger in the following respects:

- (a) Side-drift landings require higher design side loads.
- (b) Full-braked landings with vertical velocity require higher design braking loads.

The front wheel structure appears to require greater strength than the conventional tail wheel because of larger vertical and, possibly, side loads.

CONCLUSIONS

The conclusions of this study are summarized in the table. The effects of the different parameters on the various characteristics are given.

Probably the most important parameter is the longitudinal position of the center of gravity which should be

as far backward as will be permitted by the condition that the airplane shall not tip over backward in any useful loading or attitude condition.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 8, 1937.

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2. Wetmore, J. W.: The Rolling Friction of Several Airplane Wheels and Tires and the Effect of Rolling Friction on Take-Off. T.R. No. 583, N.A.C.A., 1937.

SUMMARY OF EFFECTS OF GEOMETRICAL PARAMETERS ON
CHARACTERISTICS OF TRICYCLE LANDING GEARS

Parameter Characteristic	Forward distance of c.g.	Height of c.g.	Caster length	Caster angle	Height of thrust axis	Longi- tudinal wheel base	Lateral wheel base
Directional stability	++	0	+	-	0	+	0
Take-off	--	+	0	0	--	+	0
Ground handling	--	-	+	--	-	+	++*
Steering force	--	0	--	-	0	+	0
Shimmy	--	0	-	-	-	+	0
Nosing over	--	--	0	0	-	+	++
Tipping over backward	++	--	0	0	0	0	0
Porpoising	++	-	0	0	0	0	0

* Assumes the use of differential braking.

+ or ++ Indicates that an increase in the numerical value of the parameter has a beneficial, or very beneficial, effect on the characteristic concerned.

0 Indicates that the parameter has no known effect on the characteristic.

- or -- Indicates that an increase in the numerical value of the parameter has a detrimental, or very detrimental, effect on the characteristic concerned.

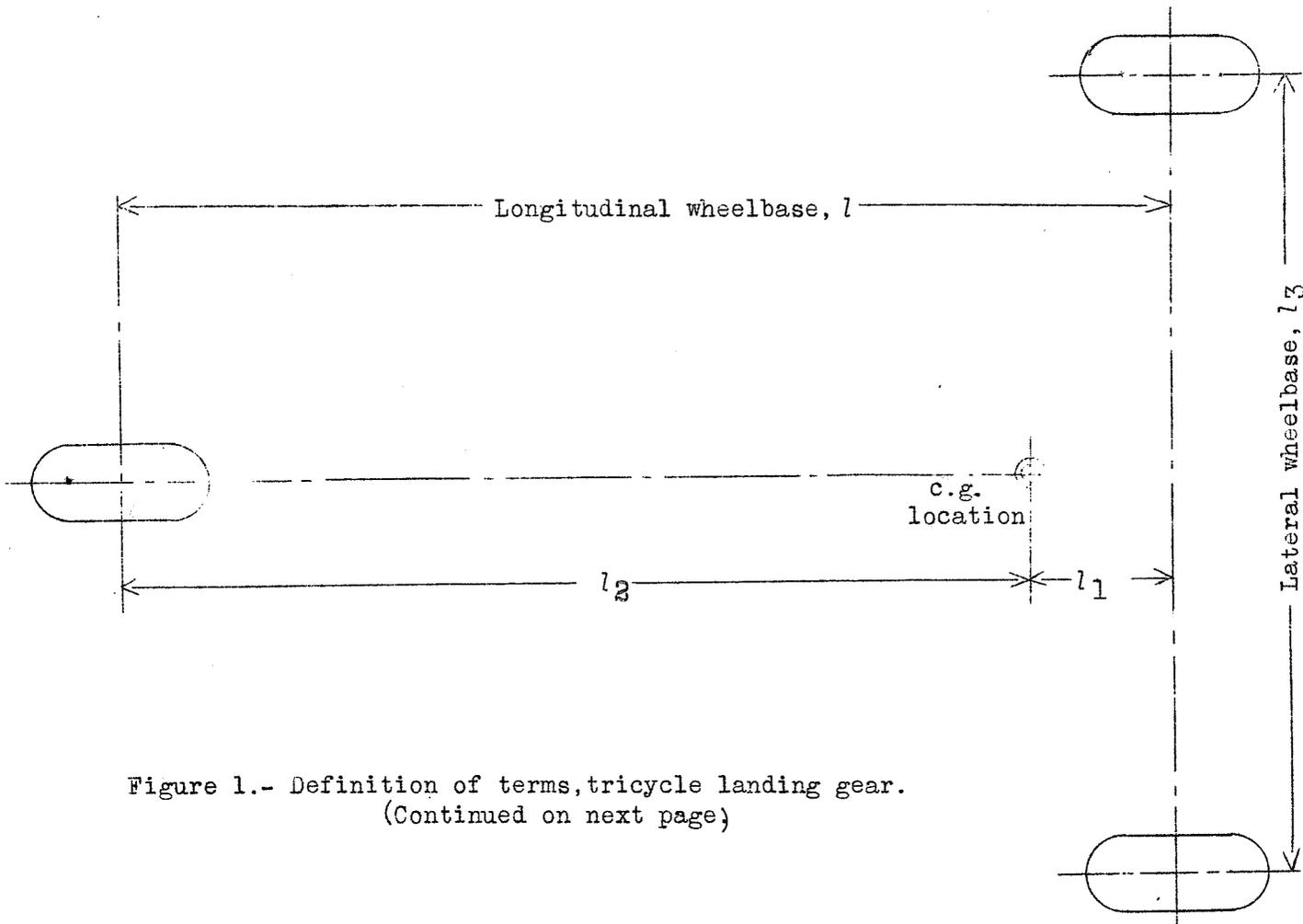


Figure 1.- Definition of terms, tricycle landing gear.
(Continued on next page)

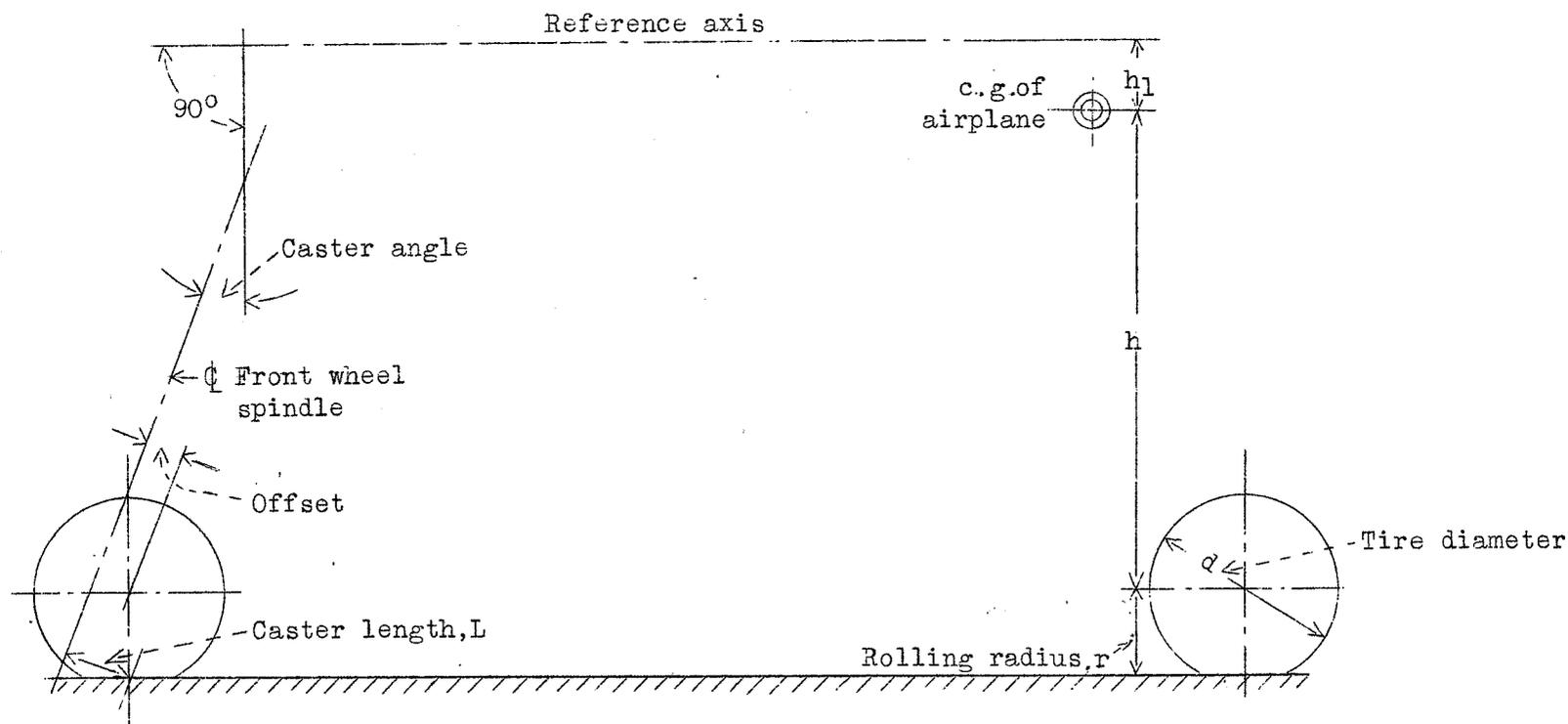


Figure 1.- Definition of terms, tricycle landing gear.
(Continuation of figure 1)

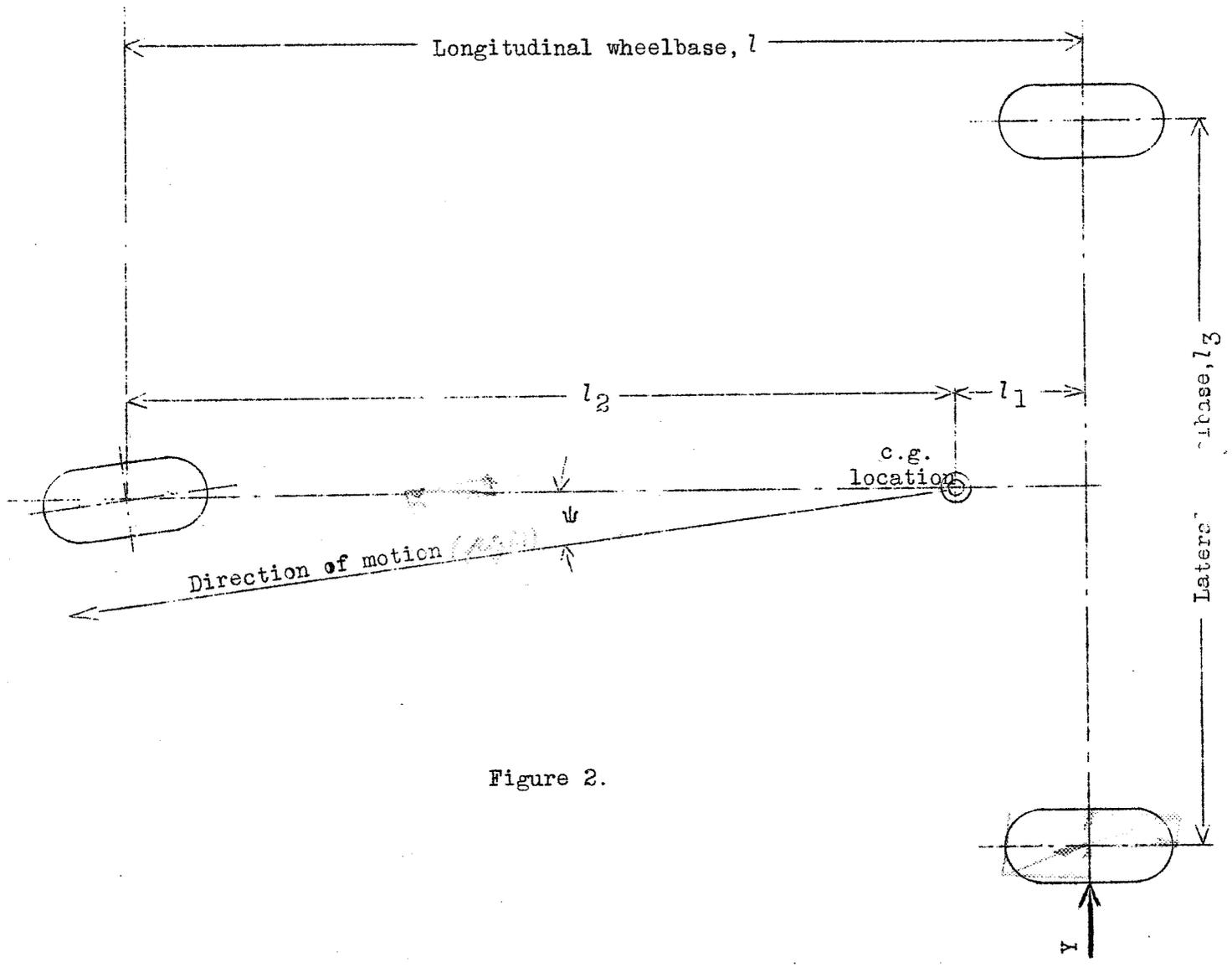


Figure 2.

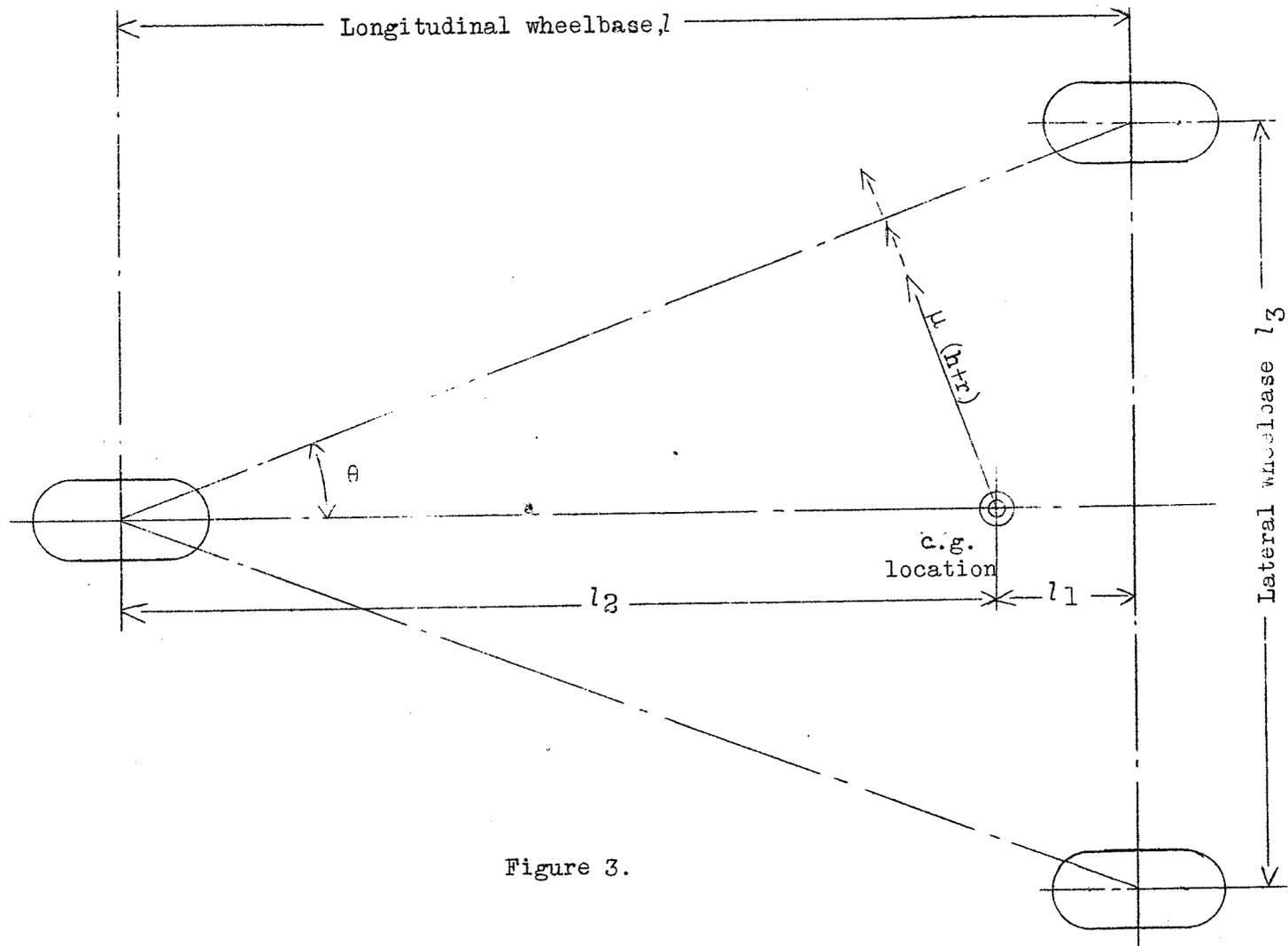


Figure 3.