Section 6.4

NATIONAL BUREAU OF STANDARDS REPORT

4574

LANDING GEAR LOADS RESULTING FROM TAXYING AIRPLANE OVER A PROJECTING RUNWAY LIGHT

Progress Report 1

To

Equipment Laboratory
Wright Air Development Center
Department of the Air Force

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

U. S. DEPARTMENT OF COMMERCE
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NBS Lab. No. 6.4/295, PR-1

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LANDING GEAR LOADS RESULTING FROM TAXYING AIRPLANE OVER A PROJECTING RUNWAY LIGHT

by

Wilhelmina D. Kroll

1. INTRODUCTION

For the modern airport, runways are being built wider in order to accomodate the larger, heavier airplanes that are coming into use. The need for better lighting of the runways has become more important with the increased traffic in night flight and with the higher landing speeds of present aircraft. Flush-mounted units have been used for runway lights so as to put no obstacle in the path of the plane as it taxies for landing or takeoff. A more efficient lighting system could be devised if the lights were mounted so as to project slightly above the runway surface. Although this type of light might be approved for lights at the sides of runways in the expectation that the airplane wheels would not run over them, they would not be used to light a runway across its intersection with another runway unless it can be shown that this would permit safe operation of all airplanes using the runway. It was the purpose of this investigation to determine what the loads on the gears of an airplane would be if, while taxying on a runway, the airplane taxied over a runway light of a particular shape and height, and what the optimum shape of light would be.

As a result of an increased number of accidents caused by collapse or failure of the landing gear, numerous studies have been made to determine the loads imposed on the structure during landing of an airplane or taxying it on a runway (references 1 - 8). Although some of these reports consider wing flexibility, it is pointed out in references 9 and 10 that slightly conservative results are obtained when wing flexibility is neglected. It was felt, therefore, that an analysis in which the airplane is represented by a two-degree-of-freedom system as is done in reference 7, would give, with sufficient accuracy, the increase of load on the landing gear when the airplane taxies over a runway light and would indicate the best shape for a projecting runway light without an excessive amount of computational effort.

2. METHOD OF ANALYSIS

The airplane is represented by a single mass riding on a system of springs and dampers with a small additional mass

representing the wheel. The two-degree-of-freedom system shown in figure 1 represents one of the landing gears of the airplane and the proportionate part of the airplane mass that it supports.

In figure 1, the portion of the airplane mass carried by one landing gear is m_1. The shock strut between the airplane and the wheel is represented by a spring and a damper. The spring constant k_1 is obtained from the load-stroke curve of the strut for slow closure, and the damping constant c from drop test data of the oleo strut. m_2 is the mass of the wheel including the parts of the shock strut that participate in the motion of the wheel. The tire is a simple spring whose constant, k_2, is given by the load-deflection curve of the tire. W is the vertical force, other than the impact force, acting on the airplane (airplane weight minus lift). W_1, then, is the part of W attributed to one landing gear.

For an airplane taxying down a smooth runway, the differential equations of motion of the masses are:

$$m_2\ddot{x}_2 + k_2x_2 - k_1(x_1-x_2) - c(\dot{x}_1-\dot{x}_2) = 0 \qquad (1a)$$

$$m_1\ddot{x}_1 + k_1(x_1-x_2) + c(\dot{x}_1-\dot{x}_2) = W_1 \qquad (1b)$$

where

x_1 is the vertical displacement of mass m_1

x_2 is the vertical displacement of mass m_2

$\ddot{x}_1$ is the acceleration of mass m_1

$\ddot{x}_2$ is the acceleration of mass m_2

(x_1-x_2) is the stroke of the shock strut

$(\dot{x}_1-\dot{x}_2)$ is the velocity of closure of the shock strut

Other symbols are defined above.

If the airplane, while taxying, hits an obstruction on the runway such as a light projecting above the runway surface, the term k_2x_2 in equation (1a), which is the force on the tire, would have to be replaced by $k_2[x_2+h(t)]$, where $h(t)$ is the height of the light at time t, or

$$m_2\ddot{x}_2 + k_2[x_2 + h(t)] - k_1(x_1-x_2) - c(\dot{x}_1-\dot{x}_2) = 0 \qquad (2a)$$

$$m_1\ddot{x}_1 + k_1(x_1-x_2) + c(\dot{x}_1-\dot{x}_2) = W_1 \qquad (2b)$$

At some time during or following the run over the light, the value of $[x_2+h(t)]$ may become zero or less than zero. This would indicate that the wheel was no longer in contact with the light or the ground but the oleo would still be partly closed. The equation to use instead of (2a) would be

$$m_2\ddot{x}_2 - k_1(x_1-x_2) - c(\dot{x}_1-\dot{x}_2) = 0 \qquad (3)$$

as the force on the tire would be zero. Equations (2b) and (3) would be solved simultaneously for the motion of the masses until $[x_2 + h(t)]$ became greater than zero again, when equations (2a) and (2b) apply.

If the stroke of the oleo strut (x_1-x_2) becomes zero or less than zero during the time the motion of the airplane is being studied, it would mean that the oleo strut was fully extended and the airplane was air borne. For this condition, the equation to be satisfied is

$$m_1\ddot{x}_1 = W_1 \qquad (4)$$

At time $t=0$ when the airplane wheel would be at the edge of the light and before it had started to run over it, the deflections of the masses are

$$x_1 = W_1\left(\frac{1}{k_1} + \frac{1}{k_2}\right) \qquad (5)$$

and

$$x_2 = W_1\left(\frac{1}{k_2}\right) \qquad (6)$$

With these values of displacement as the initial values, a modification of Newton's method was used to solve the differential equations after replacing the first and second derivatives by the following difference equations given in Appendix B of reference 11

$$\dot{x}_t = \frac{1}{\Delta t}\left[\frac{11}{6}\,x_t - 3x_{t-\Delta t} + 1.5x_{t-2\Delta t} + \frac{1}{3}\,x_{t-3\Delta t}\right] \qquad (7)$$

$$\ddot{x}_t = \frac{1}{(\Delta t)^2}\left[2x_t - 5x_{t-\Delta t} + 4x_{t-2\Delta t} - x_{t-3\Delta t}\right] \qquad (8)$$

and defining $h(t)$ by a particular shape of light. By this method, a time history of the motion of the masses and of the loads on the landing gear was obtained.

The 6 different shaped lights shown in figure 2 were used to determine which was the optimum shape. Each light had a center portion 6 inches long and 3 inches high with fairings to the center section in the shape of a triangle, circular arc, ellipse, parabola or sine curve. The lengths of the trapezoidal-shaped lights were determined by varying the base angle from 5 degrees to 45 degrees in 5 degree steps. The 9 lengths of light corresponding to these angles for the trapezoidal light, table 1, were then used for the remaining shapes of light. The lights drawn in figure 2 have a length of 18.87 in. which is the length of the trapezoidal-shaped light with a base angle of 25 degrees and a maximum height of 3 inches.

The load-deflection curves of the tire and of the shock strut for a particular airplane were used in the computation. The damping constant was determined from the drop test data for the landing gear of the airplane. The strut stroke and the force on the oleo as a function of time were read from the records of a particular drop test. The spring force was read from the load-stroke curve of the shock strut for slow closure. The damping force is the difference between the oleo force and the spring force. The velocity of closure was obtained from the slope of the stroke-time curve. In reference 12, the damping force in an oleo strut was found to vary as $v^{1.46}$. For our purpose, it was believed to be sufficiently accurate to consider the damping force proportional to $v^{1.5}$. Although it is realized that the oleo strut exhibits different characteristics in extension than it does on compression, it was assumed that the strut would have the characteristics associated with its compressive action at all times.

3. ANALYSIS FOR REAR MAIN GEAR OF THE B-47 AIRPLANE

As the data needed in our study were available for the B-47 airplane, reference 13, it was decided to use this airplane in our first study. The data are given in table 2. The load-

deflection curve for the tire, and the load-stroke curve for the shock strut are given in figures 3 and 4, respectively. The curves of figures 5 and 6 were used to obtain, in conjunction with figure 4, the damping constant as a function of stroke. With the data from these curves and from table 2, the time histories of the displacements of the masses were obtained in SEAC, Standards Eastern Automatic Computer.

4. RESULTS FOR B-47 REAR MAIN GEAR AND DISCUSSION

Figure 7 shows the time history of the compression of the tire, $x_2 + h(t)$, as the airplane taxies at 10 miles per hour over a rectangular-shaped light of the dimensions given in figure 2. The corresponding loads on the tire are obtained from the load-deflection curve of the tire, figure 3.

Figure 8 shows the time history of the compression of the tire as the airplane taxies over the series of trapezoidal-shaped lights of the lengths given in table 1. Results for the other shaped lights, circular arc, ellipse, parabola, and sine, were very similar to those for the trapezoidal light, the only difference being in the slope of the curve from time 0 to the maximum value of tire deflection.

The loads corresponding to the maximum compression of the tire are given in table 3. Although these loads are quite high, particularly for the shorter length lights, they are below the values that would cause tire bottoming and it is assumed, therefore, that the landing gear could safely take these loads.

It is noted from table 3 that for the longest light, the trapezoidal shape seems to be best as the load on the tire is least for that light. For all other lengths of light, the maximum difference in impact load for the shapes studied did not exceed 3 percent. This would indicate that the shape of the light was not important and that any of the shapes investigated could be used. This result agrees with that of reference 14 where it was found that the obstacle edge had little effect on the vertical loads in the main gears when taxying a B-36 airplane over obstacles from 1.5 to 4.5 inches high.

In a later series of tests on the B-36 airplane, reference 15, it was reported that taxying over a platform obstacle (20 ft long) produced a more severe loading condition than taxying over a short obstacle (1 ft long). From our analysis, the loads seem to be more severe for the short obstacle but are of

shorter duration. See figure 8. However, a comparison of the time histories of the displacements of the airplane and wheel masses for the longest and shortest trapezoidal lights, figure 9, shows that taxying over the longer light causes a greater rebound of the masses. This could result in undesirable loading, particularly if the airplane taxied over a series of these lights as was done with the B-36.

5. ANALYSIS FOR THE NOSE GEAR OF THE F-86H AIRPLANE

After completing the analysis for the B-47 airplane, it was decided to make a similar one for the nose wheel of a fighter aircraft. The F-86H airplane was chosen for this study. As it was found in the previous work that the shape of light has little, if any, effect on the loads on the tire as the airplane taxies over the light, it was decided to limit our study on the F-86H to the trapezoidal shape of light.

Four heights of light were used, 0.75, 1.00, 1.25, and 1.50 inches. A base angle of 14 degrees was used to determine the length of lights for these heights. This value of base angle was decided upon since it had been used in a preliminary design of a runway light and would be about the largest base angle that could be tolerated because of other considerations such as snow removal from runway, et cetera. The dimensions of the lights are given in figure 10 which shows the relative size of the 4 lights to be studied. Taxying speeds of 50, 80, 110, and 140 miles per hour were used for each light. For this series of computations, it was assumed that the nose wheel carried the entire portion of the airplane weight attributed to it, i.e., lift was not taken into account. To determine the effect of lift, however, four of the cases were repeated in which W_1 had a value of 900 pounds, approximately half of the weight used in the first computation. Other data for the F-86H airplane (reference 16) are given in table 2. The load-deflection curve for the tire is given in figure 11. The damping coefficient and load-stroke curves were obtained, as previously described, from data in references 16 and 17. The time histories of the displacement of the masses were computed in SEAC. Loads corresponding to the wheel displacement were obtained from figure 11.

6. RESULTS FOR F-86H NOSE GEAR AND DISCUSSION

The results obtained for the lowest light, figure 10(a), are shown in figure 12 for the 4 taxying speeds investigated.

In taxying over this particular light, the compression of the tire and therefore the load on it was approximately the same, about 5,000 lb for all taxying speeds. After the wheel is over the light, the shock strut extends slightly but soon returns with small oscillations to its initial position when taxying. The extension of the strut after the first compression is largest for the slowest taxying speed.

A comparison of the maximum impact loads, table 4, shows larger differences between the loads obtained for the lowest and the highest taxying speeds as the height of light is increased from 0.75 inch to 1.50 inches. It is also evident from table 4 and figure 13 that, as the height of the light is increased, the compression of the tire and therefore the load on it, for any particular taxying speed is larger and the extension of the shock strut greater following its rolling over the light.

The time histories of the displacement of the part of the airplane mass attributed to the nose gear and of the wheel mass are shown in figure 14 considering no lift or $W_1 = 1811$ lb. These are for taxying speeds of 50 and 140 mph. In order to determine the effect of lift, these cases were recomputed assuming that the part of the airplane mass attributed to the nose gear was only about 50 percent of its previous value or $W_1 = 900$ lb. A comparison of the figures shows that lift of this order of magnitude on the airplane would reduce the tire deflection by about 0.24 in., or the load by about 1,000 lb and, at the lower speed of taxying, would cause the wheel to lift off the ground. It is to be noted that the time histories of the displacement of the airplane mass show a very slight movement, much smaller than it was in the case of the main rear gear of the B-47 airplane, figure 9. This would indicate that all of the reaction of a nose wheel running over a light of 0.75 in. in height was taken by the shock strut with little discernable reaction on the airplane. One would not expect a pitching of the airplane even though the nose gear raised off the ground.

6. CONCLUSIONS

From the preliminary studies made on the main rear wheel of the B-47 airplane and the nose wheel of the F-86H airplane, the following conclusions seem to be indicated regarding the landing gear loads resulting from taxying an airplane over a raised runway light:

1. The height of light is an important factor in the magnitude of the landing gear loads but the shape of the light edge has little, if any, effect.

2. At high taxying speeds, there is little reaction of the F-86H airplane when its nose wheel taxies over a raised runway light of moderate height.

3. At high taxying speeds, the landing gear loads increase as the height of the light is increased, and, somewhat less, as the taxying speeds increase. The latter may be offset by an increase in lift at the higher taxying speeds.

7. RECOMMENDATIONS

On the basis of the results obtained, it is recommended that:

(1) Analyses be made of other representative landing gears using the SEAC code developed for the present study.

(3) The application of the analysis to the landing condition be investigated.

For the Director,

B L Wilson
B. L. Wilson, Chief,
Engineering Mechanics Section,
Division of Mechanics.

Washington, D. C.
March 1956

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Table 1. Lengths of light used in study of B-47 rear main landing gear.

Case	Base angle, degrees	Length, inches
1	5	74.58
2	10	40.02
3	15	28.40
4	20	22.48
5	25	18.87
6	30	16.39
7	35	14.57
8	40	13.15
9	45	12.00

Table 2. Data for B-47 and F-86H airplanes.

B-47 Airplane - Rear Main Gear

Unsprung weight - 2200 lb
Weight of airplane - 180,300 lb
Weight support by rear main gear - 108,200 lb or 54,100 lb per wheel
At time t=0, under weight supported by rear gear

$$x_1 = 15.01 \text{ in.}$$

$$x_2 = 4.11 \text{ in.}$$

Taxying speed - 10 miles/hr or 176 in./sec
W_1 = 48,700 lb (weight supported by wheel reduced 10 percent to account for lift)

F-86H Airplane - Nose Wheel

Unsprung weight - 60 lb
Weight attributed to nose wheel, W_1 = 1811 lb
At time t=0, under weight supported by nose wheel

$$x_1 = 6.845 \text{ in.}$$

$$x_2 = 0.665 \text{ in.}$$

For $W_1 = 900$ lb

$$x_1 = 4.53 \text{ in.}$$

$$x_2 = 0.43 \text{ in.}$$

Table 3. Maximum load on rear main gear of B-47 when taxying over runway lights 3 inches high at 10 miles per hour.

Case	Length of light, in.	Maximum load, lb					
		Rectangle	Trapezoid	Circular arc	Ellipse	Parabola	Sine curve
1	74.58	-	70,800	74,800	79,500	74,200	76,000
2	40.02	-	85,900	85,500	86,700	84,200	86,500
3	28.40	-	90,300	90,200	90,000	89,900	90,300
4	22.48	-	92,200	91,500	91,300	91,100	91,800
5	18.87	-	93,600	94,800	93,000	92,000	92,500
6	16.39	-	96,000	95,000	94,000	94,200	94,000
7	14.57	-	96,200	96,200	95,300	94,800	94,900
8	13.15	-	97,000	97,000	96,100	96,600	96,600
9	12.00	-	97,000	97,200	96,800	96,800	96,700
10	3.00	100,000	-	-	-	-	-

Table 4. Maximum loads on nose wheel of F-86H when taxying over trapezoidal light

Case	Height of light, in.	W_1, lb	Velocity of airplane mi/hr	Velocity of airplane in./sec	Maximum deflection of tire in.	Maximum load on tire, lb
1a	0.75	1811	50	880	1.360	4860
1b		1811	80	1408	1.375	4910
1c		1811	110	1936	1.393	5010
1d		1811	140	2464	1.390	4990
1e		900	50	880	1.108	3740
1f		900	140	2464	1.153	3930
2a	1.00	1811	50	880	1.530	5630
2b		1811	80	1408	1.625	6070
2c		1811	110	1936	1.620	6040
2d		1811	140	2464	1.645	6150
3a	1.25	1811	50	880	1.760	6690
3b		1811	80	1408	1.800	6870
3c		1811	110	1936	1.870	7200
3d		1811	140	2464	1.895	7300
4a	1.50	1811	50	880	1.895	7300
4b		1811	80	1408	2.043	8000
4c		1811	110	1936	2.070	8130
4d		1811	140	2464	2.092	8230
4e		900	50	880	1.590	5900
4f		900	80	1408	1.787	6820

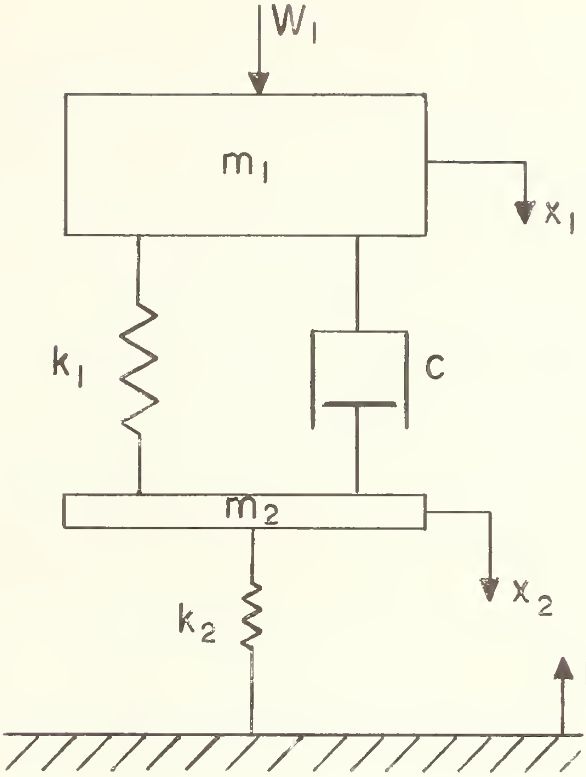

Fig. 1 Representation of airplane.

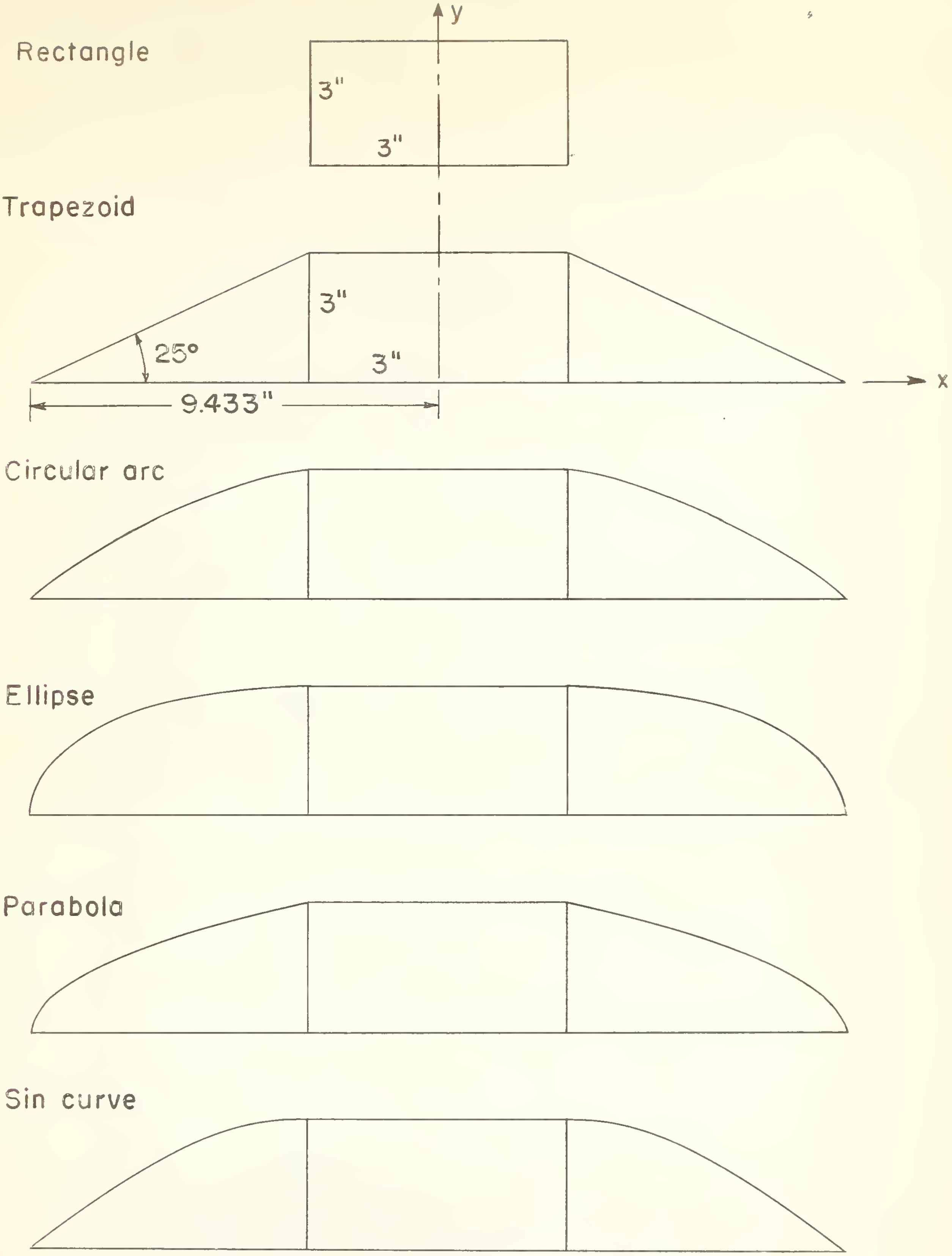

Fig.2 Shapes of lights investigated.

Fig. 3 Load-deflection curve for tire of B-47 rear main gear.

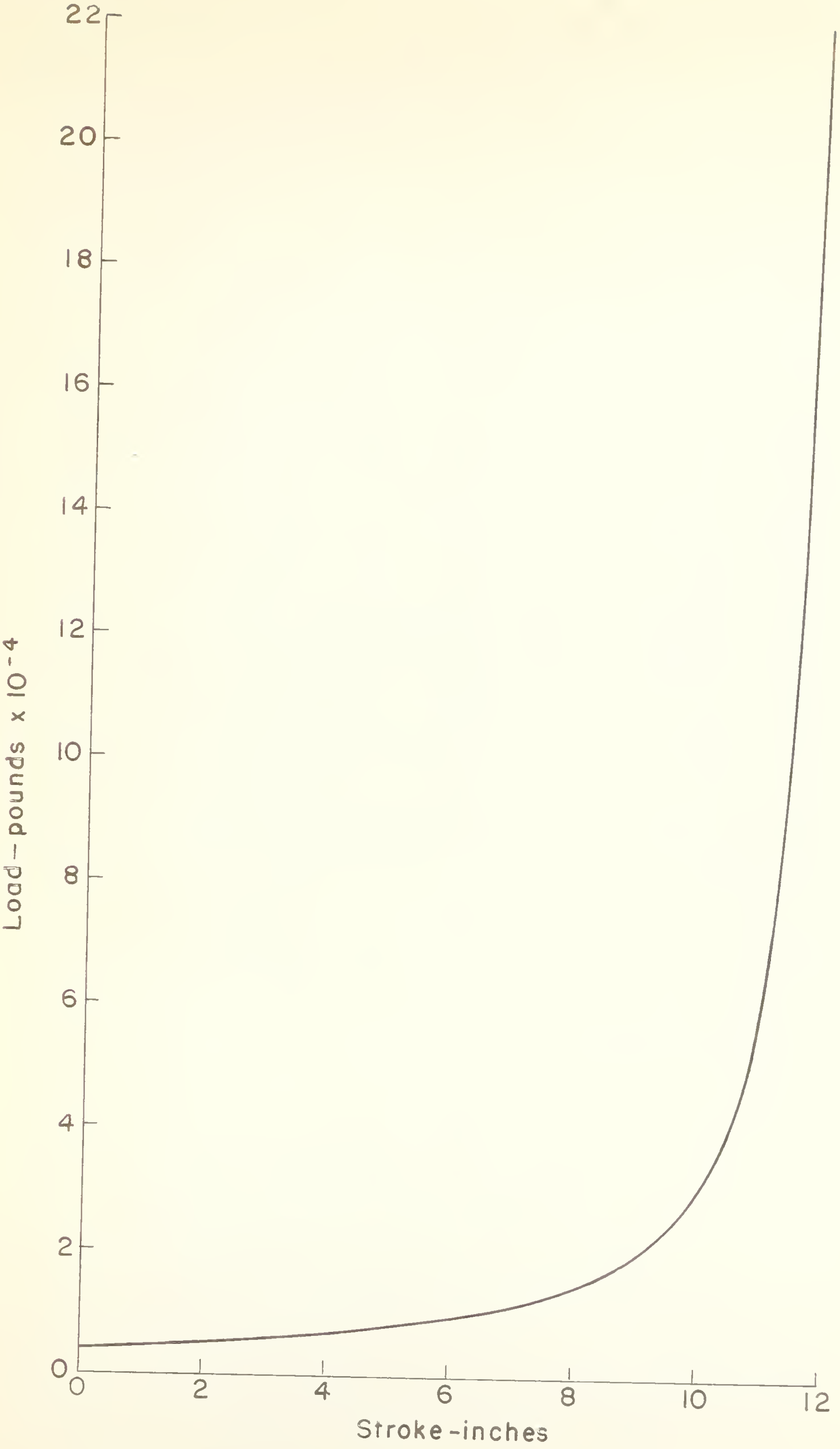

Fig. 4 Static load-stroke curve for B-47 rear main gear.

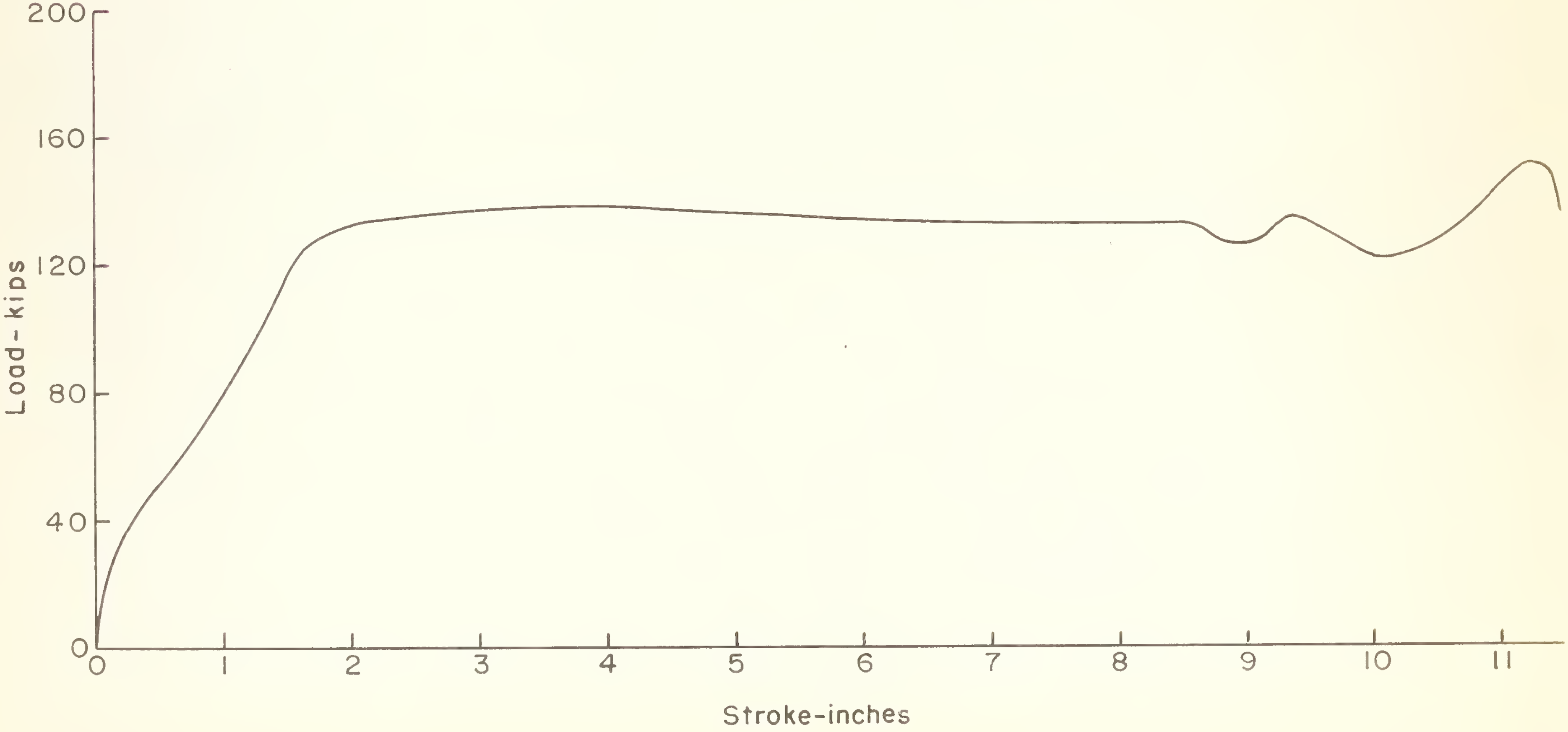

Fig. 5 Dynamic load-stroke curve for B-47 rear main gear.

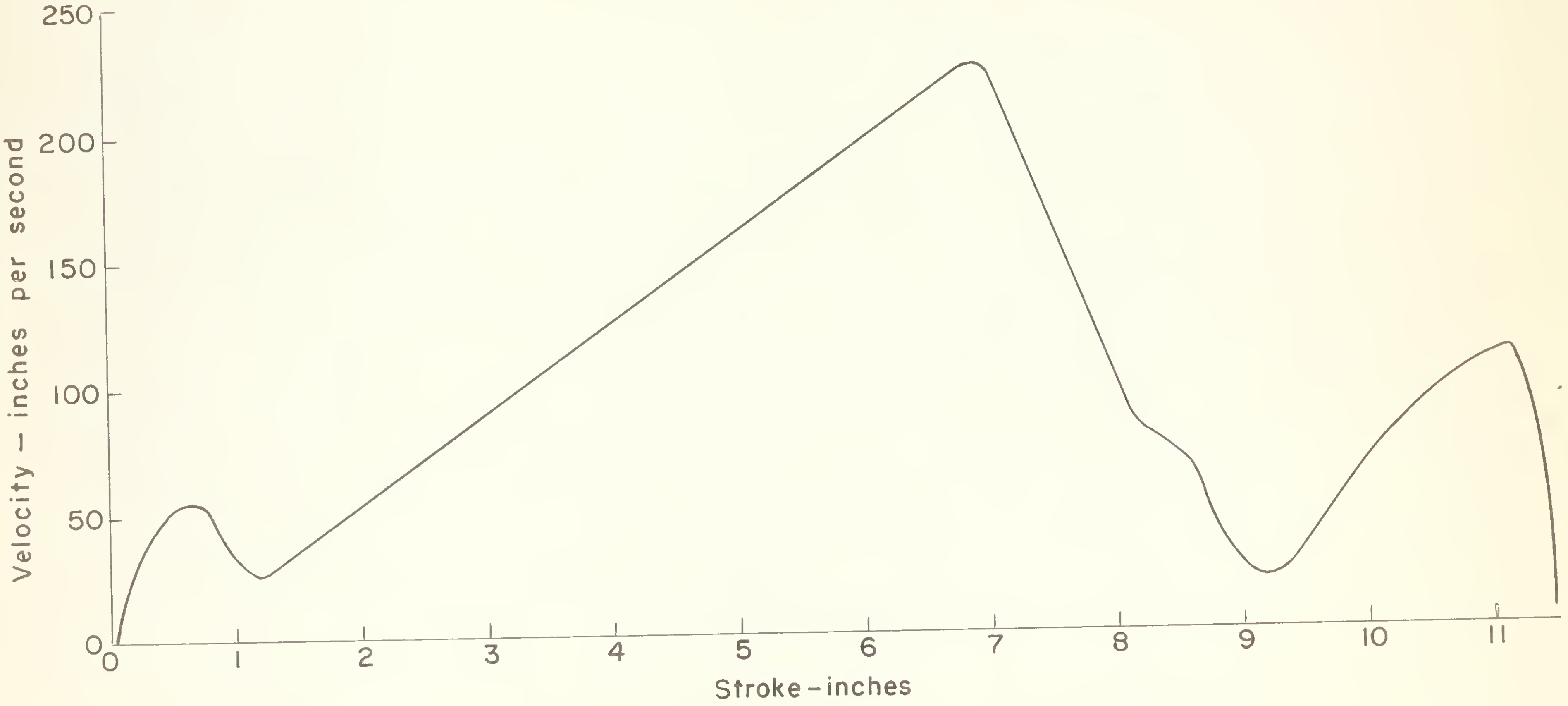

Fig. 6 Velocity-stroke curve for B-47 rear main gear.

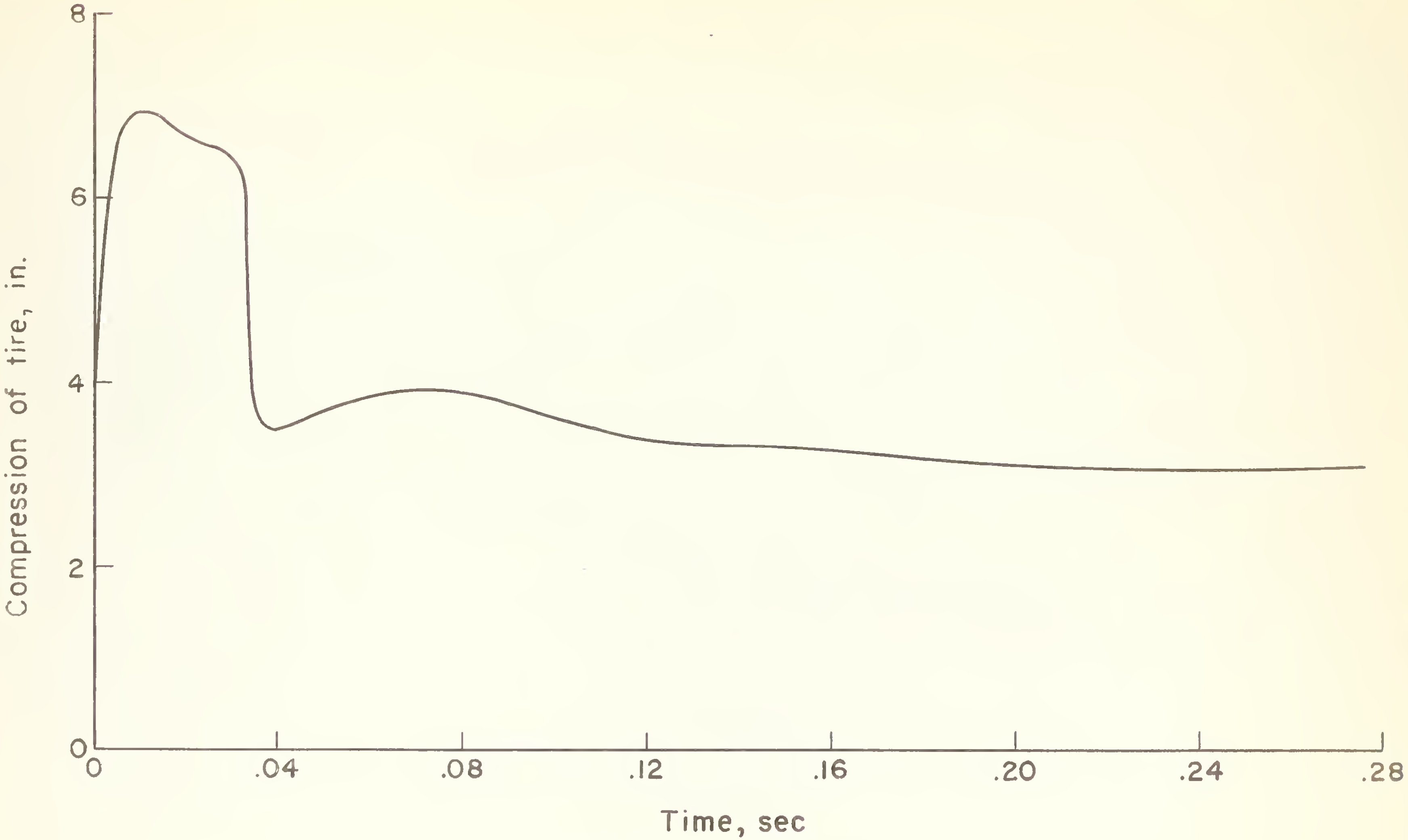

Fig. 7 Time history of compression of tire due to airplane taxying over square-shaped light. Height of light = 3 in.

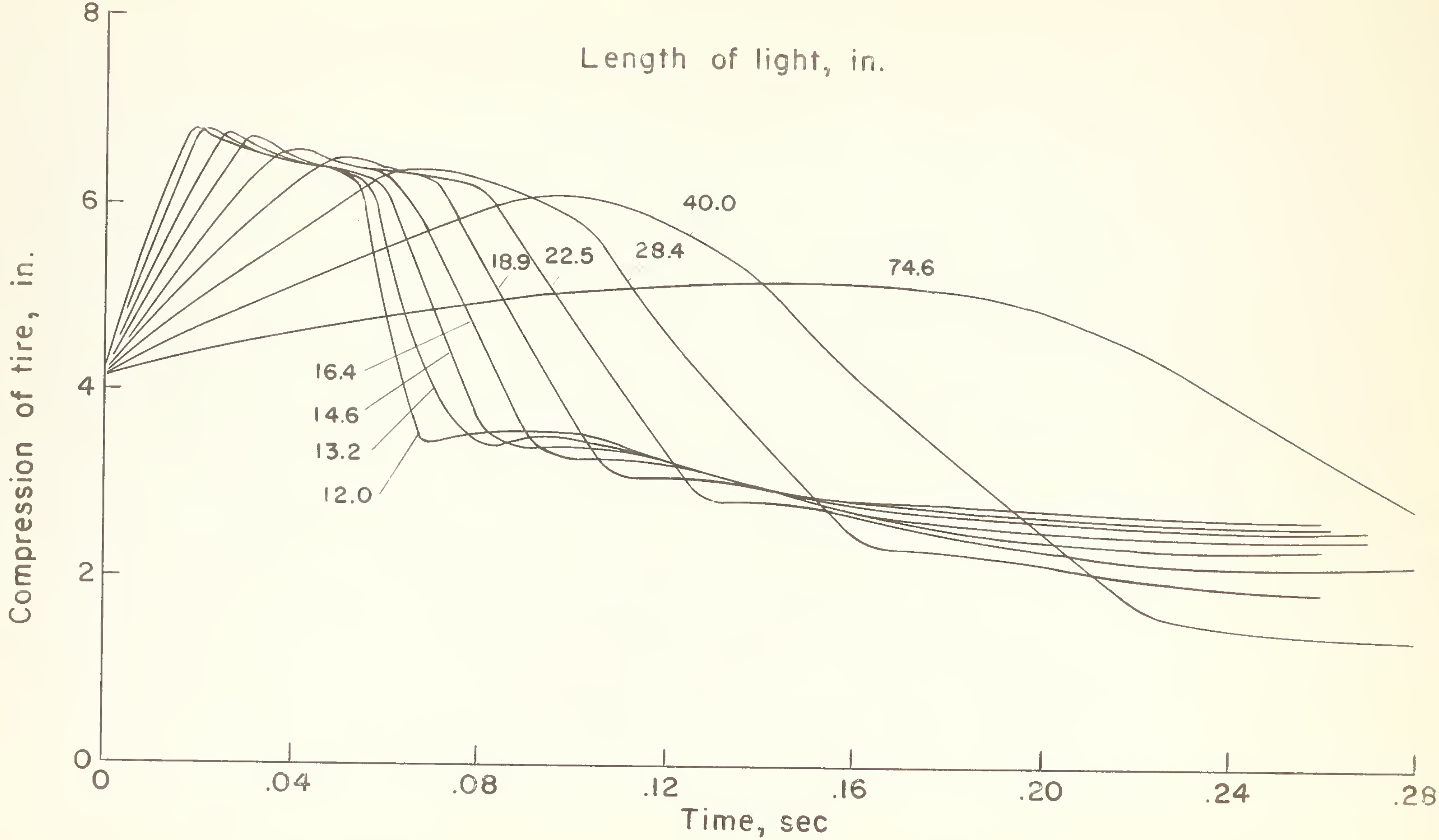

Fig. 8 Time history of compression of tire due to airplane taxying over trapezoidal-shaped lights. Maximum height of light = 3 in.

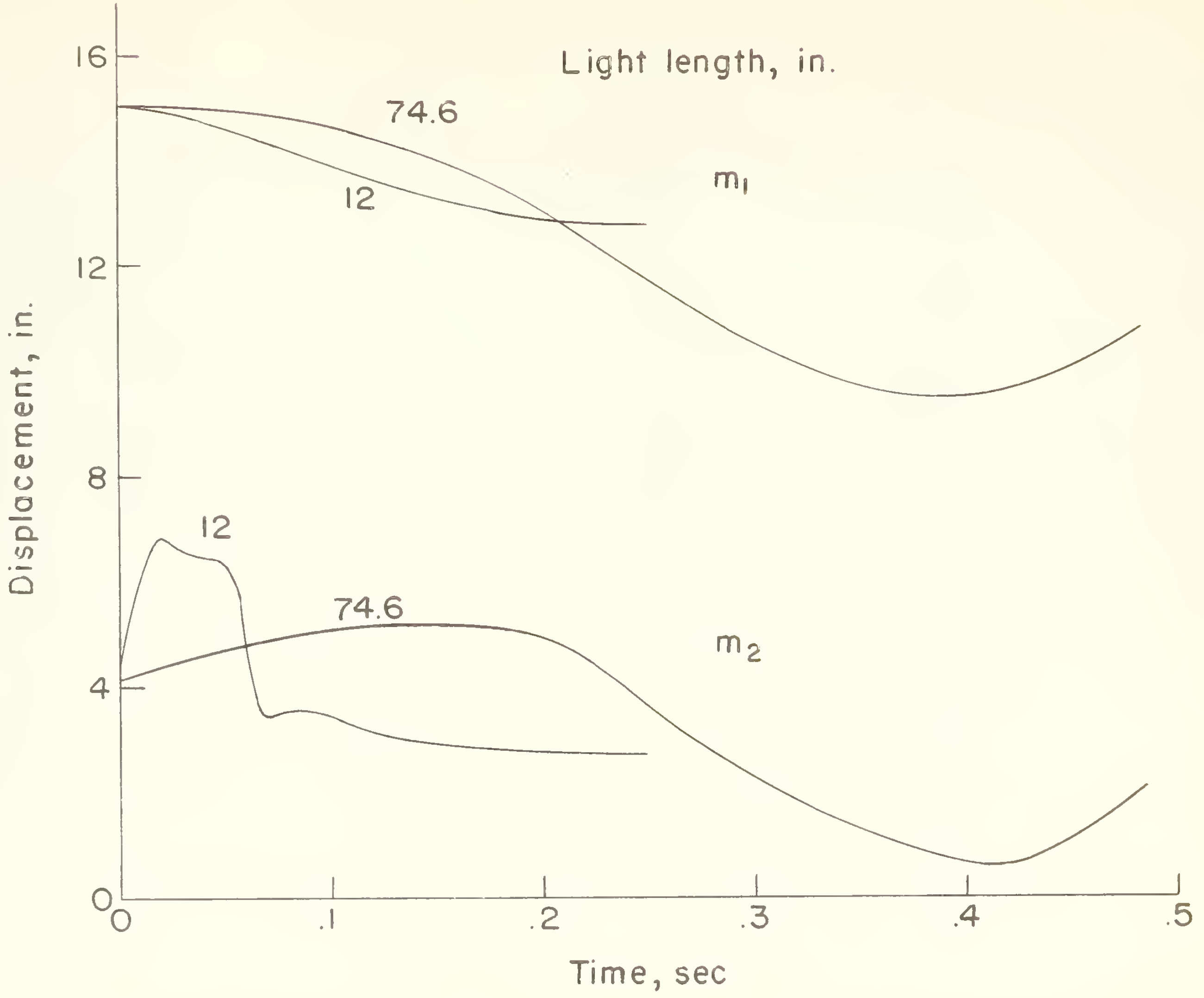

Fig. 9 Displacement of airplane, m_1, and wheel, m_2, of B-47 when taxying over trapezoidal light, 3 in. high, at 10 mph.

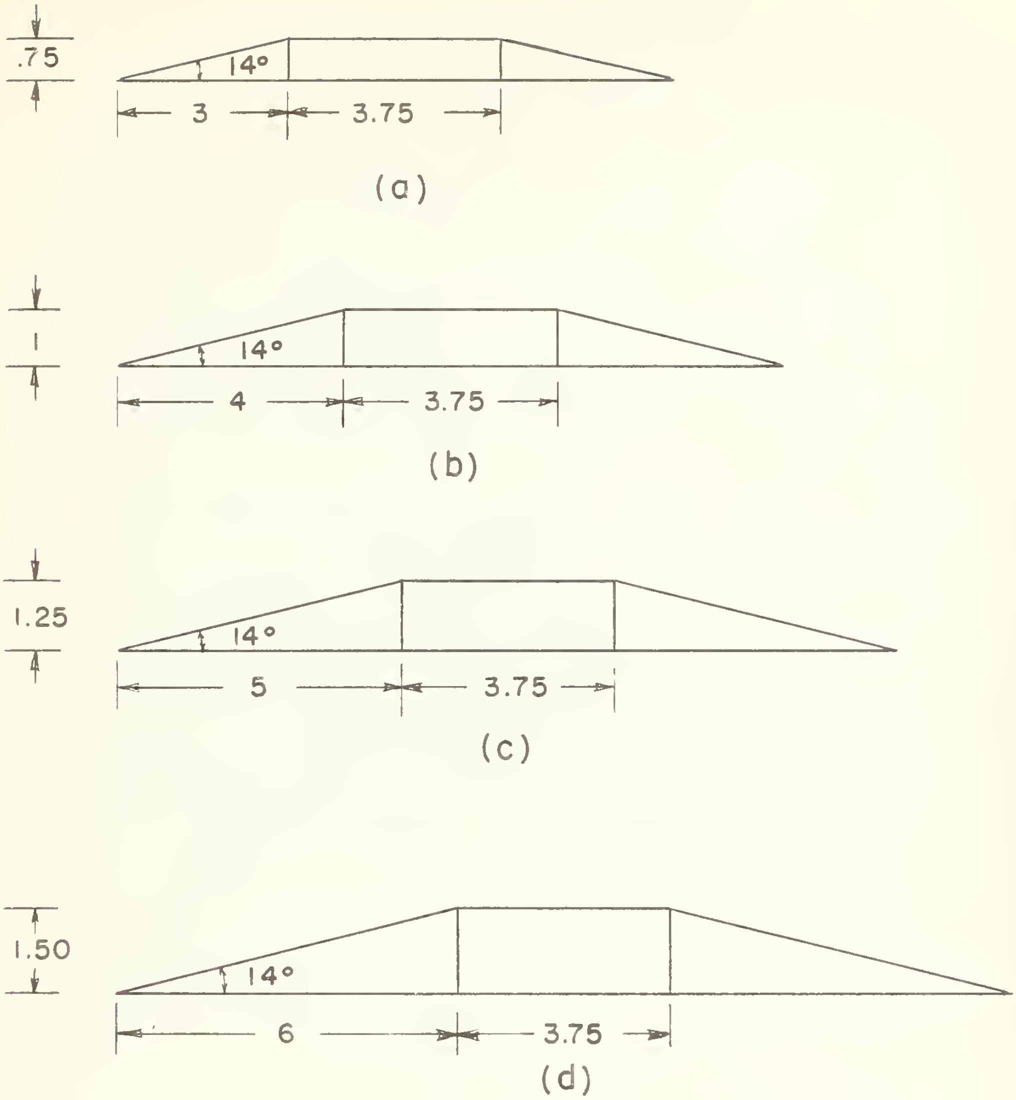

Fig. 10 Lights used in F-86H nose gear study.
(Dimensions in inches)

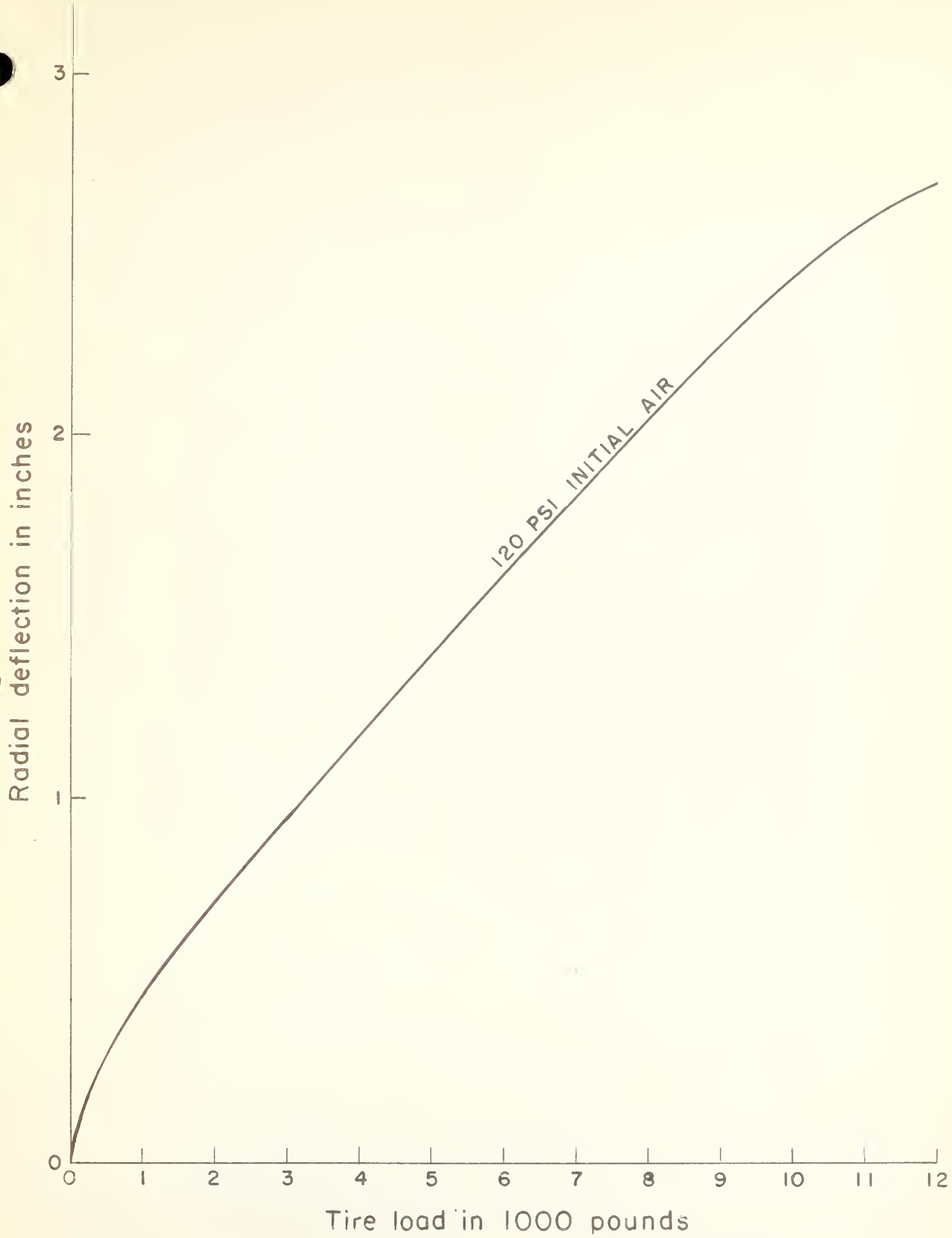

Fig. 11 Load-deflection curve for tire of F-86H nose wheel.

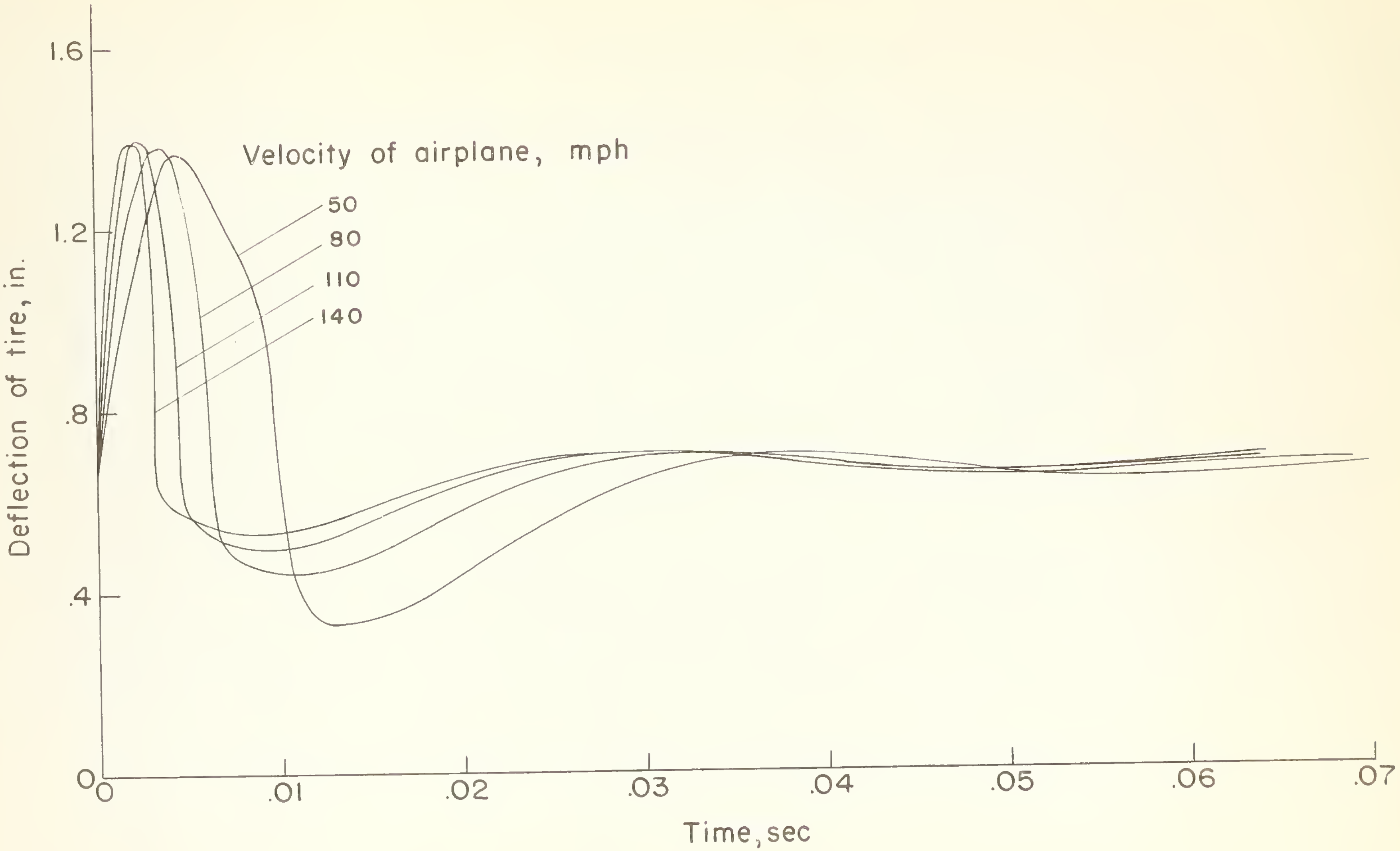

Fig. 12 Time history of deflections of nose wheel tire when taxying F-86 over a runway light 0.75 in. high at various speeds.

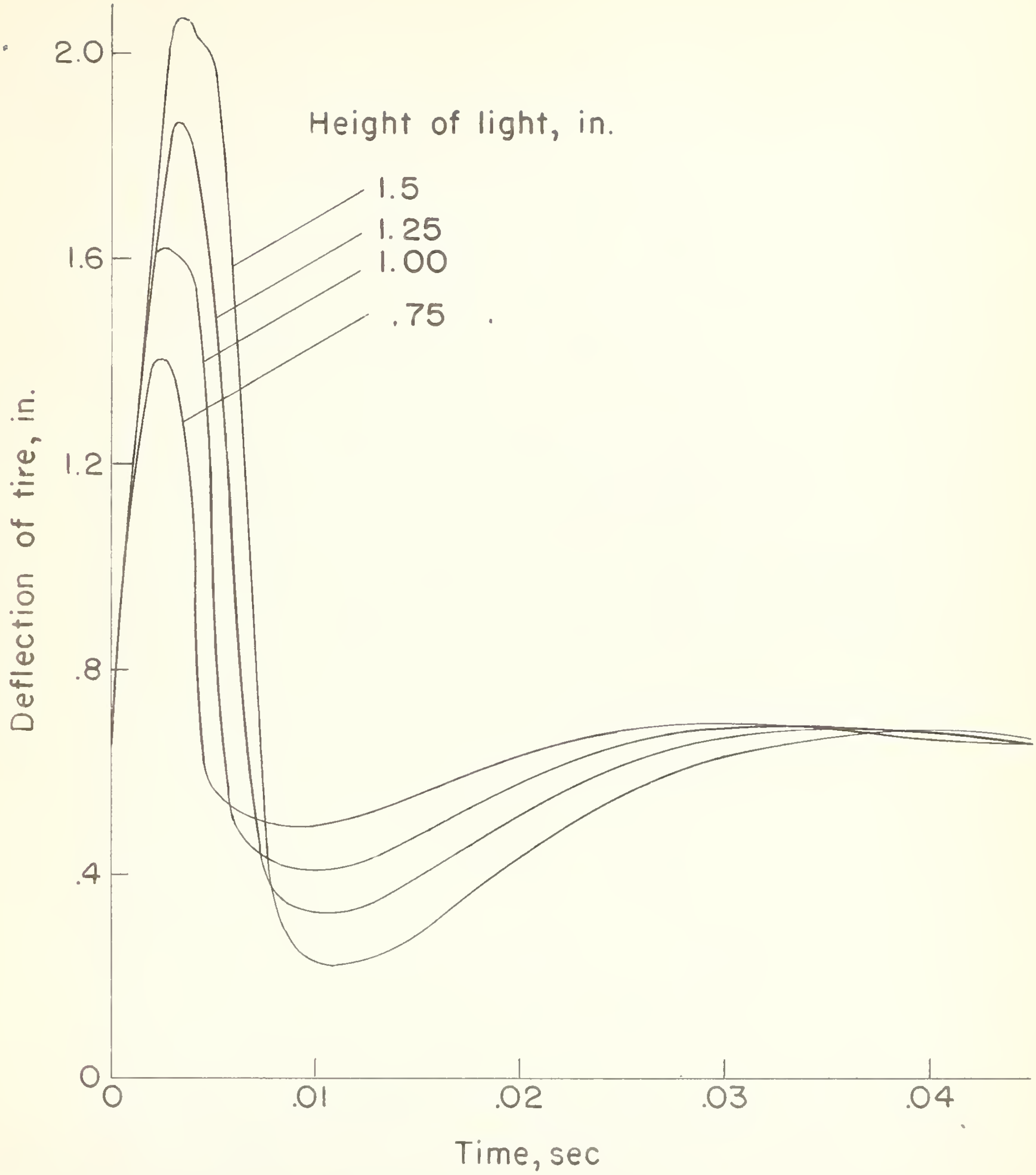

Fig. 13 Deflection of tire of nose wheel as F-86H airplane is taxied over trapezoid lights of different heights at 110 mph.

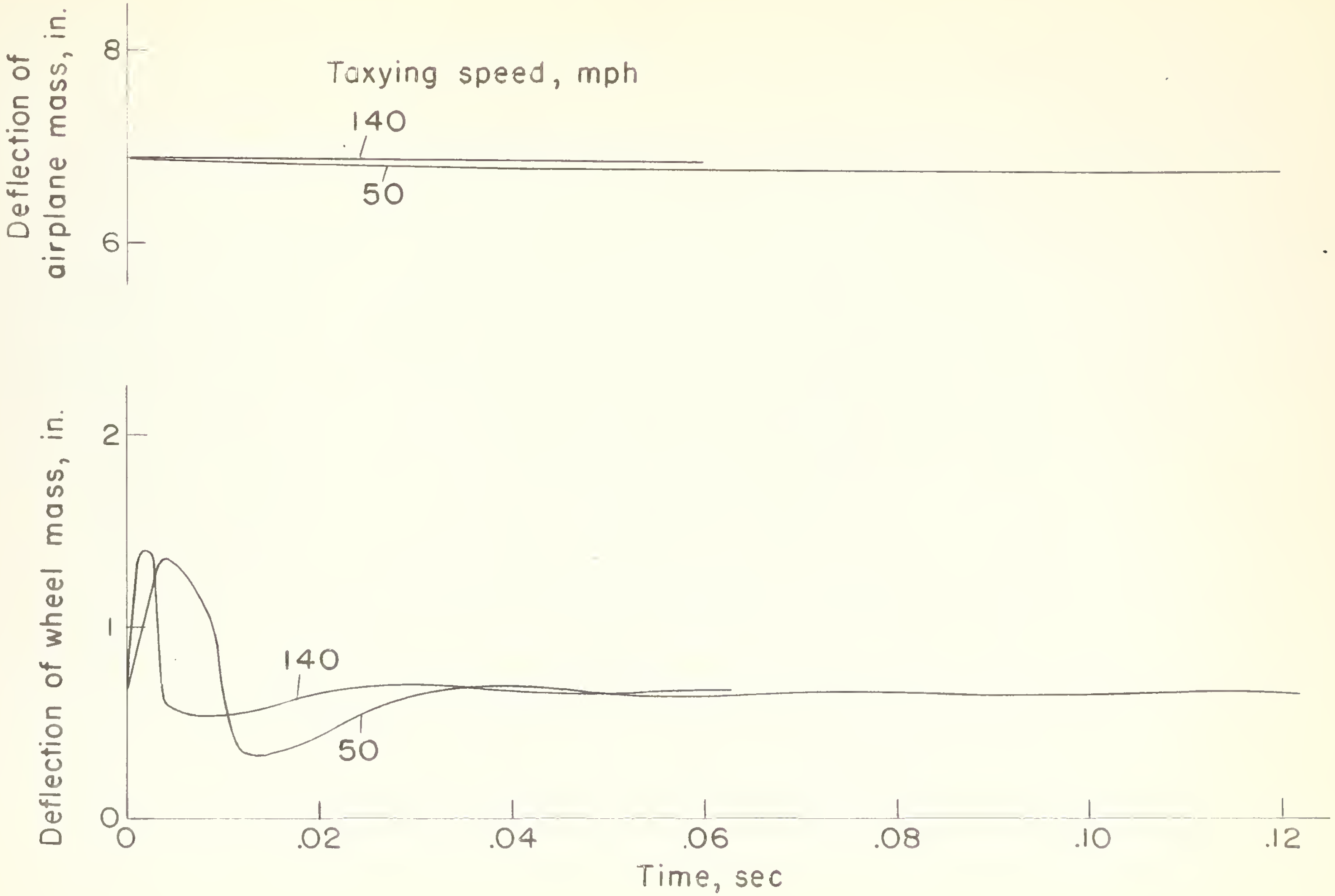

Fig. 14 Displacement of airplane and of wheel when taxying over trapezoidal light 0.75 in. high. *$W_1 = 1811$ lb.*

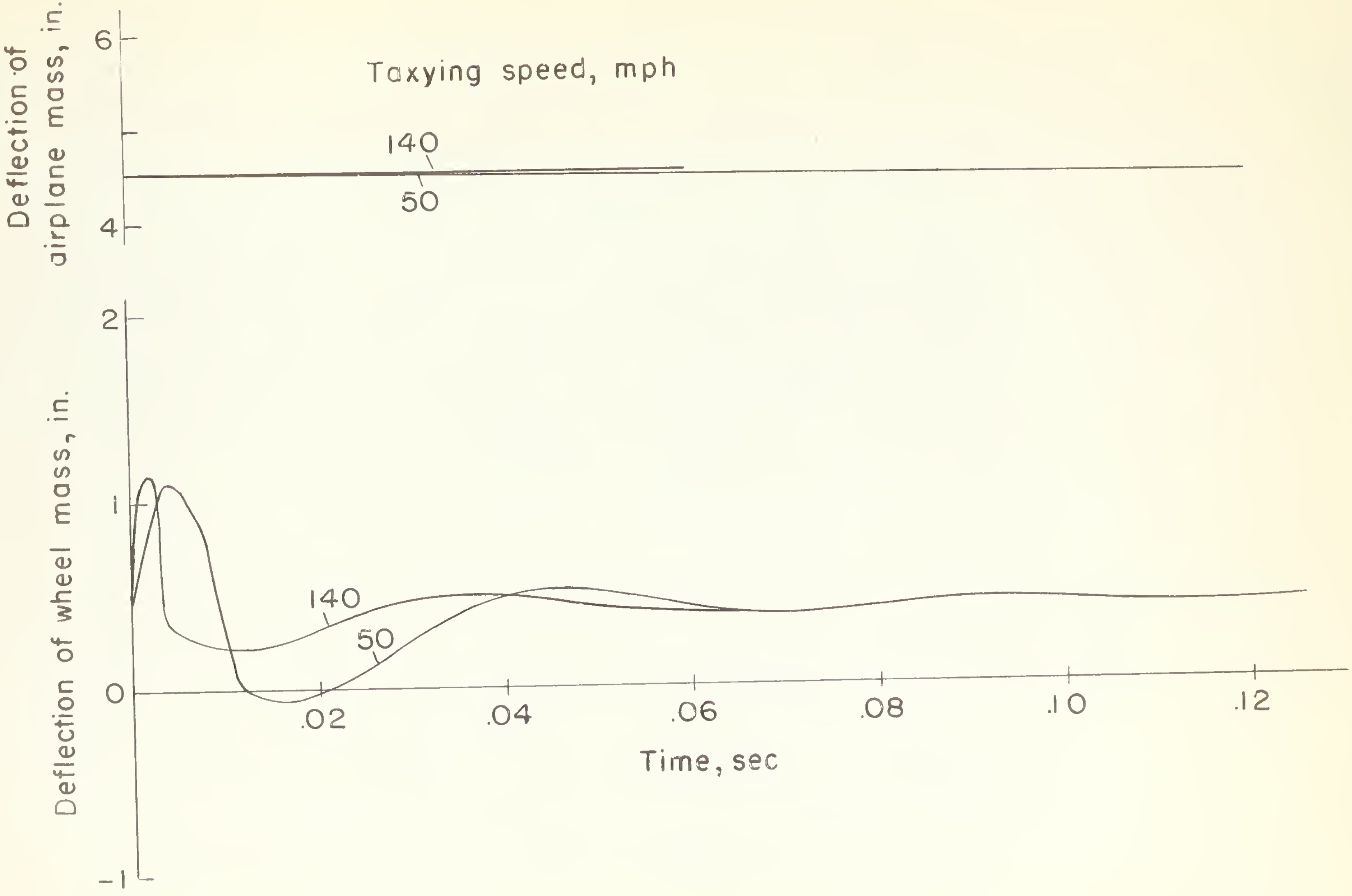

Fig. 15 Displacement of airplane and of wheel when taxying over trapezoidal light 0.75 in. high. $W_1 = 900$ lb

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