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ADJUSTMENT OF STICK FORCE BY A NONLINEAR AILERON-STICK LINKAGE

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By John G. Lowry

It is a well-known fact that the aileron-stick force can be varied by changing the mechanical advantage of the control system. This principle is herein applied to an aileron installation in which the stick forces are small over the low-deflection range and excessively large at full deflection. If the stick forces at full deflection are lowered to desirable values by an increase in the balancing moment, the balance at low deflections is very critical and overbalance is probable as a result of structural irregularities. Reduction of the excessively high stick forces at full deflection with a nonlinear linkage increases the stick forces over the low-deflection range and gives a more nearly linear variation of stick force with stick deflection.

Inasmuch as a system that could be determined mathematically rather than by trial and error was desirable, the subject linkage was based on a sine curve. The system is shown schematically in figure 1 and the derivation of the equations for the system is given in the appendix. The aileron-stick motion and mechanical advantage are given for equal up-and-down deflections by the following equations:

$$\delta_a = \sin^{-1}\left[\frac{R_2}{R_3}\sin\left(\frac{R_1}{R_2}\delta_s\right)\right] \qquad (1)$$

$$\frac{d\delta_a}{d\delta_s} = \frac{R_1}{R_3}\left[\frac{\cos\left(\frac{R_1}{R_2}\delta_s\right)}{\cos\delta_a}\right] \qquad (2)$$

for which the radii and angles are shown in figure 1. In order to obtain any desired mechanical advantage at full aileron deflection, equations (1) and (2) must be solved simultaneously. For convenience, it is suggested that R_2

be given a value of unity and the values of R_1 and R_3 found.

The design chart (fig. 2) was constructed as a quick method for solving the equations. This chart gives the relationship of δ_a and θ, which represents $(R_1/R_2)\delta$ for various values of R_3 and k. The symbol k is used for $\frac{d\delta_a}{d\delta_s}\Big/\frac{R_1}{R_3}$ and represents the fraction of $(d\delta_a/d\delta_s)_{\delta_a=0}$ for any aileron deflection δ_a. When the maximum values of δ_a, δ_s, and the desired value of k for full deflection are known, the values of R_1 and R_3, as well as the relationships between δ_a and δ_s and between $d\delta_a/d\delta_s$ and δ_s, can be found. The values of θ and R_3 can be determined from the value of δ_a for full deflection and the desired value of k. Dividing θ by δ_s gives the value of R_1 because the chart is based on $R_2 = 1$. By use of the values of R_1 and R_3, the value of $d\delta_a/d\delta_s$ is determined. When the values of R_1 and R_3 are known, the values of δ_s and $d\delta_s/d\delta_a$ for partial aileron deflection can be found. If greater accuracy is needed in determining $d\delta_a/d\delta_s$, it is recommended that this value be computed from equation (2) by use of the values of R_1 and R_3 from the chart.

By use of the aileron-stick motion as shown in figure 3, the stick forces were computed for a modern fighter airplane and were compared with the computed stick forces based on a straight-line linkage (fig. 4). The two curves in figure 4 are based on the same maximum values of δ_a and δ_s. This comparison shows that the sine differential decreased the maximum stick force by about 9 pounds, or 35 percent, with only a slight increase in the stick forces for small aileron deflections.

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APPENDIX

DERIVATION OF EQUATIONS FOR THE SYSTEM

Equal up-and-down aileron deflection.- By use of the schematic diagram of the sine linkage (fig. 1) the equations for aileron deflection δ_a and mechanical advantage $d\delta_a/d\delta_s$ were derived as follows:

The connection between the stick crank R_1 and crank 2, R_2 is direct; therefore,

$$\theta = \frac{R_1}{R_2}\delta_s \tag{3}$$

Because the link is long compared with R_2 and R_3, its angularity can be neglected.

$$R_2 \sin\theta = R_3 \sin\delta_a \tag{4}$$

Combining equations (3) and (4) gives

$$\sin\delta_a = \frac{R_2}{R_3}\sin\left(\frac{R_1}{R_2}\delta_s\right) \tag{5}$$

therefore the value of δ_a for any value of δ_s is

$$\delta_a = \sin^{-1}\left[\frac{R_2}{R_3}\sin\left(\frac{R_1}{R_2}\delta_s\right)\right] \tag{6}$$

Because the mechanical advantage is the slope of the aileron-stick deflection curve, differentiating equation (5) gives

$$\frac{d\delta_a}{d\delta_s} = \frac{R_1}{R_3}\left[\frac{\cos\left(\frac{R_1}{R_2}\delta_s\right)}{\cos\delta_a}\right] \tag{7}$$

Unequal up-and-down aileron deflection.- It is believed that the variation in $d\delta_a/d\delta_s$ is also useful when the deflections of the ailerons are not equal; therefore crank 2 was rotated through an angle ϕ and the equations were derived in the same manner as for equal up-and-down aileron deflections. The resulting equations are

$$\delta_a = \sin^{-1}\left[\frac{R_2}{R_3}\sin\left(\phi + \frac{R_1}{R_2}\delta_s\right) - \frac{R_2}{R_3}\sin\phi\right] \qquad (8)$$

$$\frac{d\delta_a}{d\delta_s} = \frac{R_1}{R_3}\,\frac{\cos\left(\phi + \frac{R_1}{R_2}\delta_s\right)}{\cos\delta_a} \qquad (9)$$

Simultaneous solution of equations (8) and (9) for the two end limits of δ_a and one of the end limits of $d\delta_a/d\delta_s$ gives the values of R_1, R_3, and ϕ.

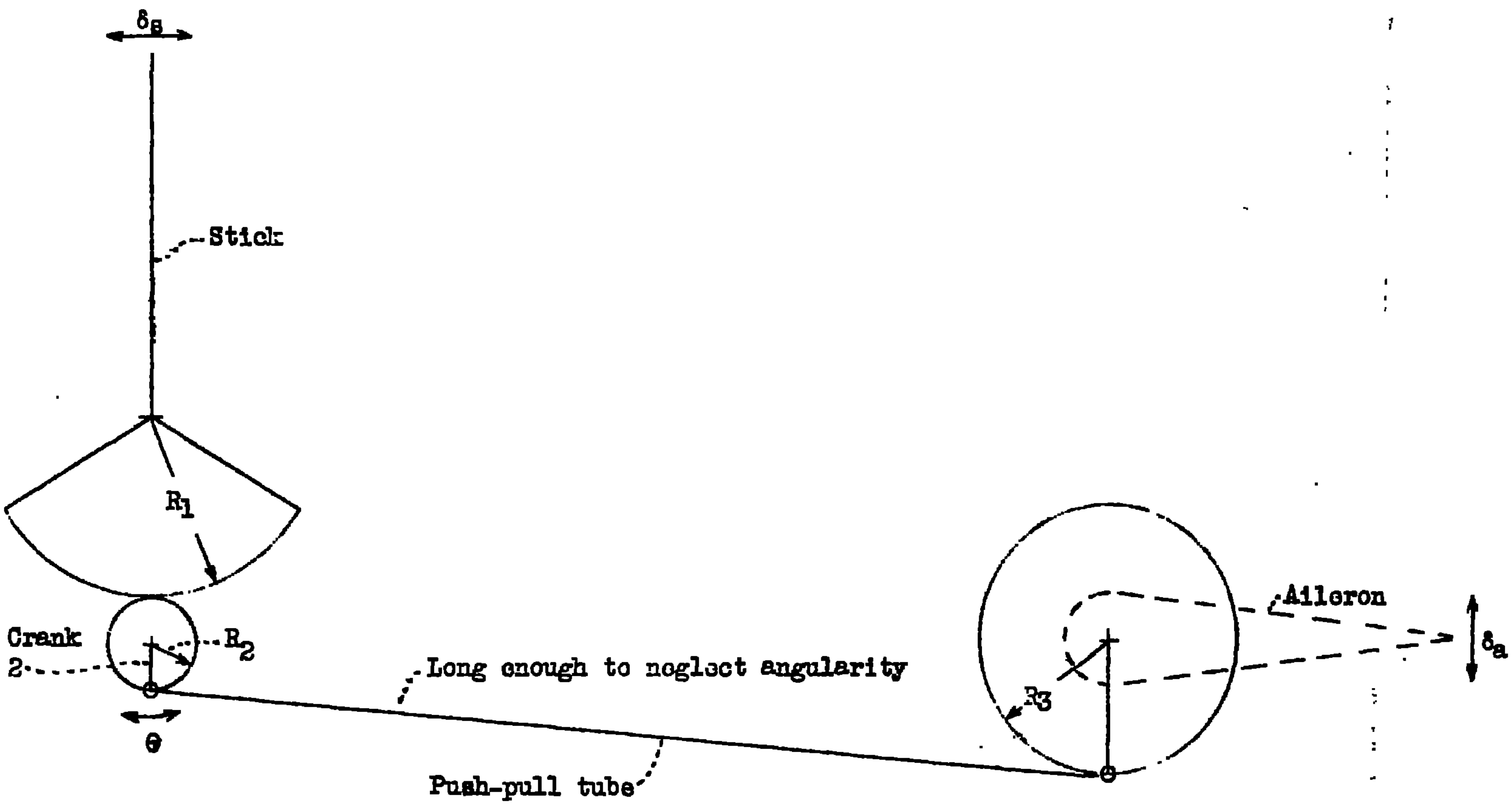

Figure 1.- Schematic diagram of sine linkage.

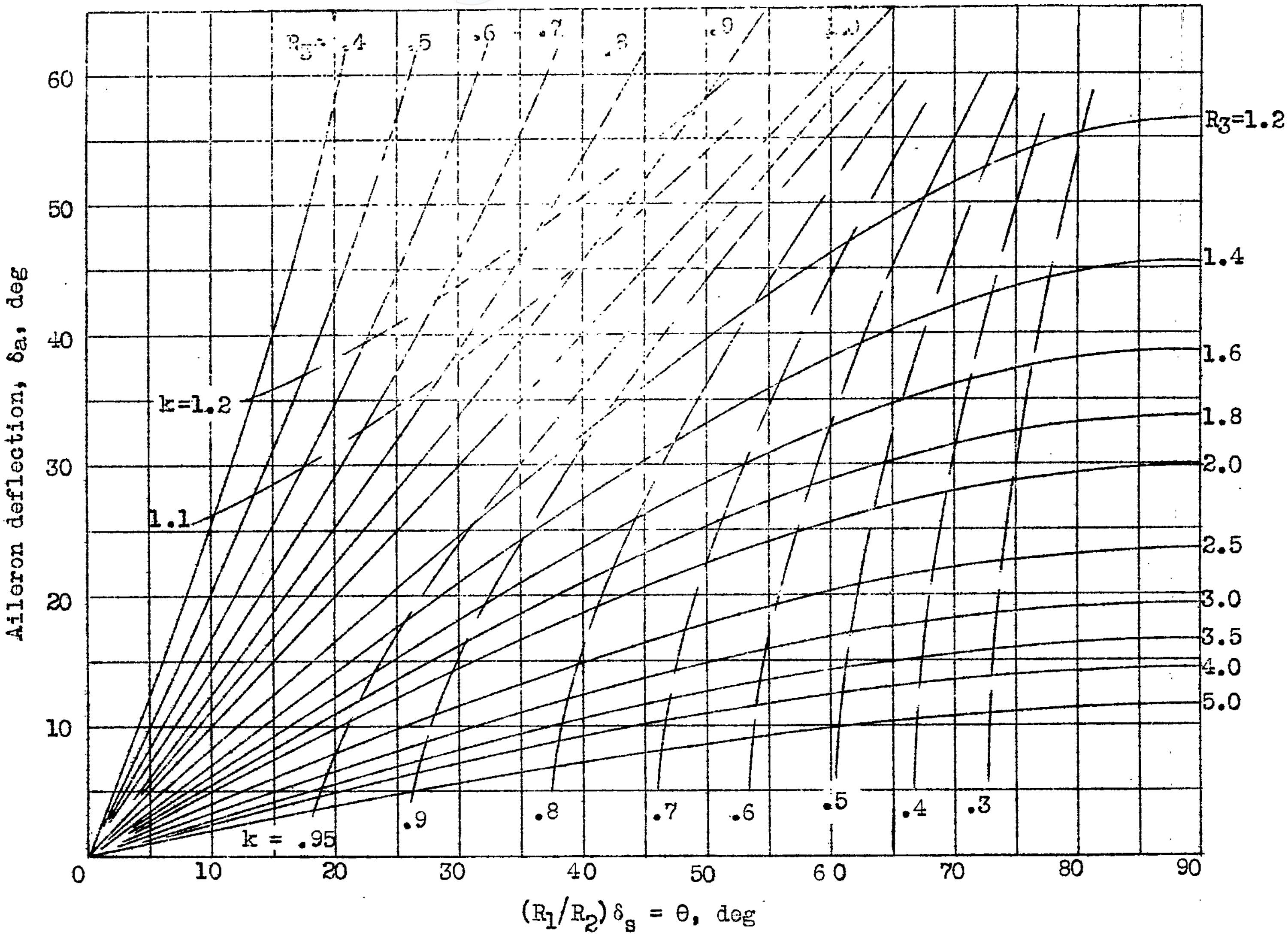

Figure 2.- Design chart for sine linkage.

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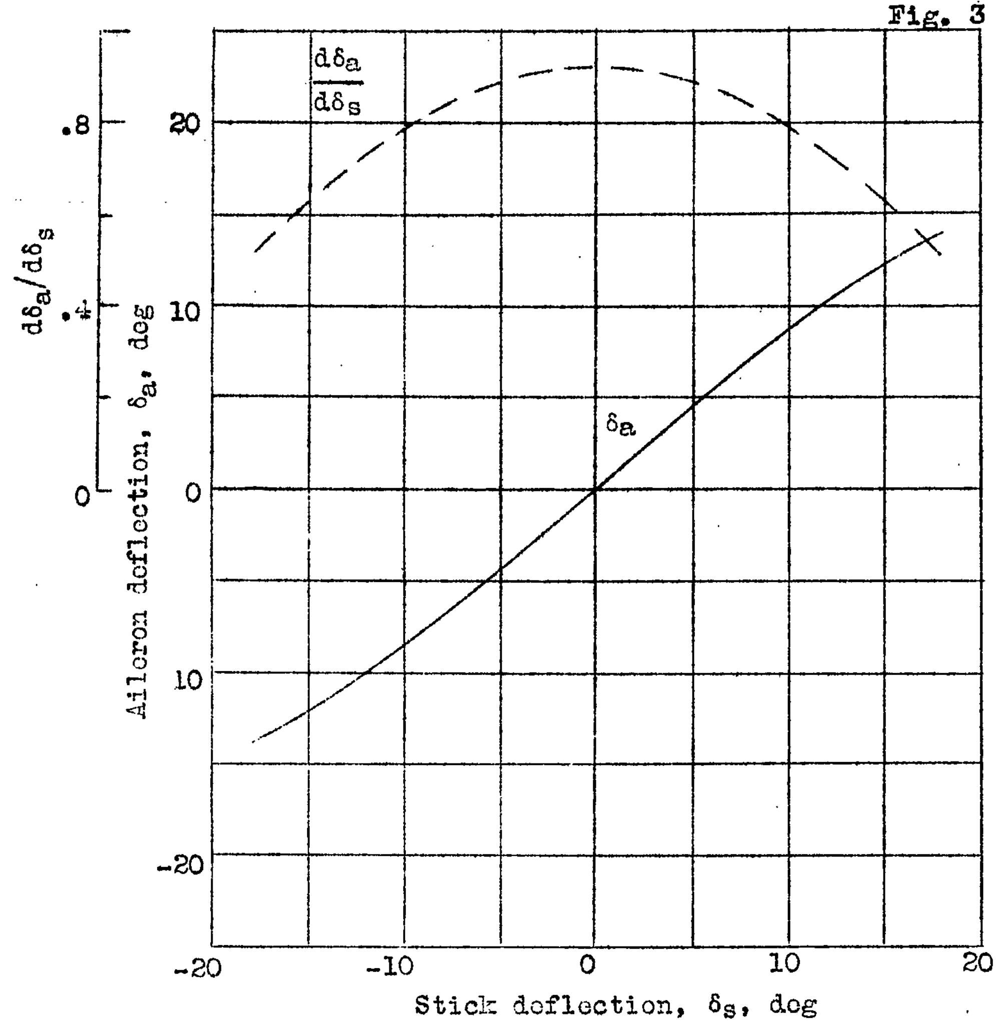
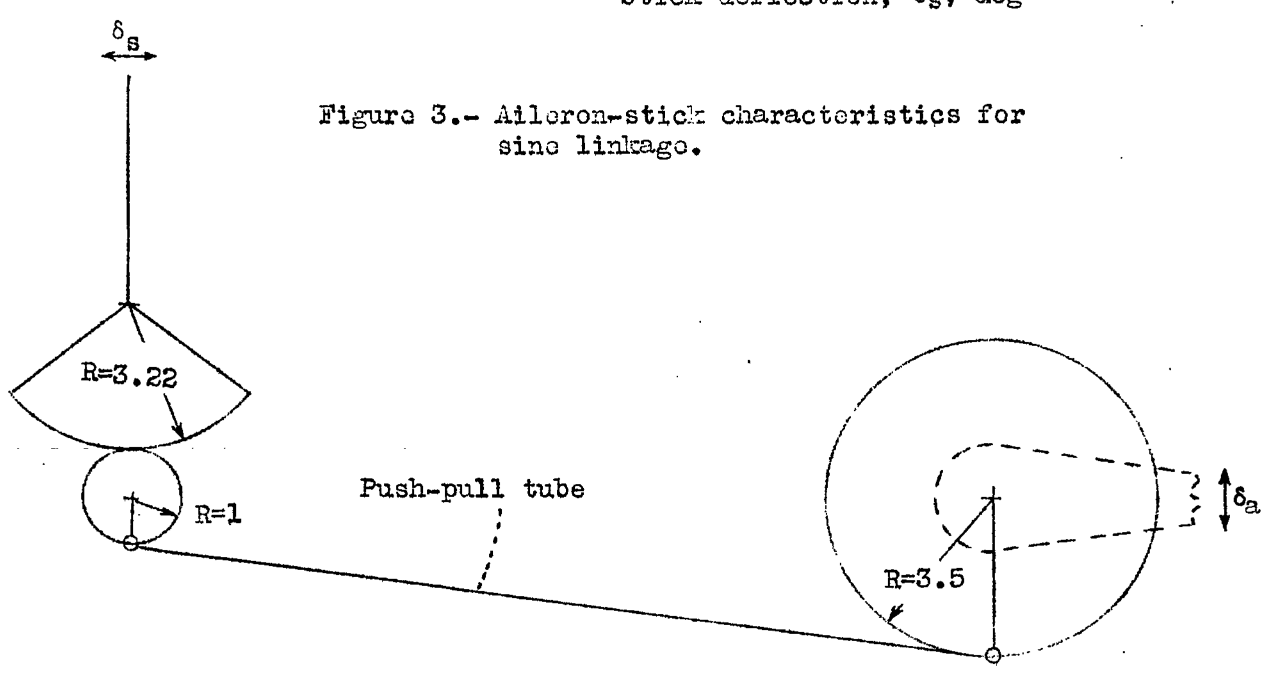
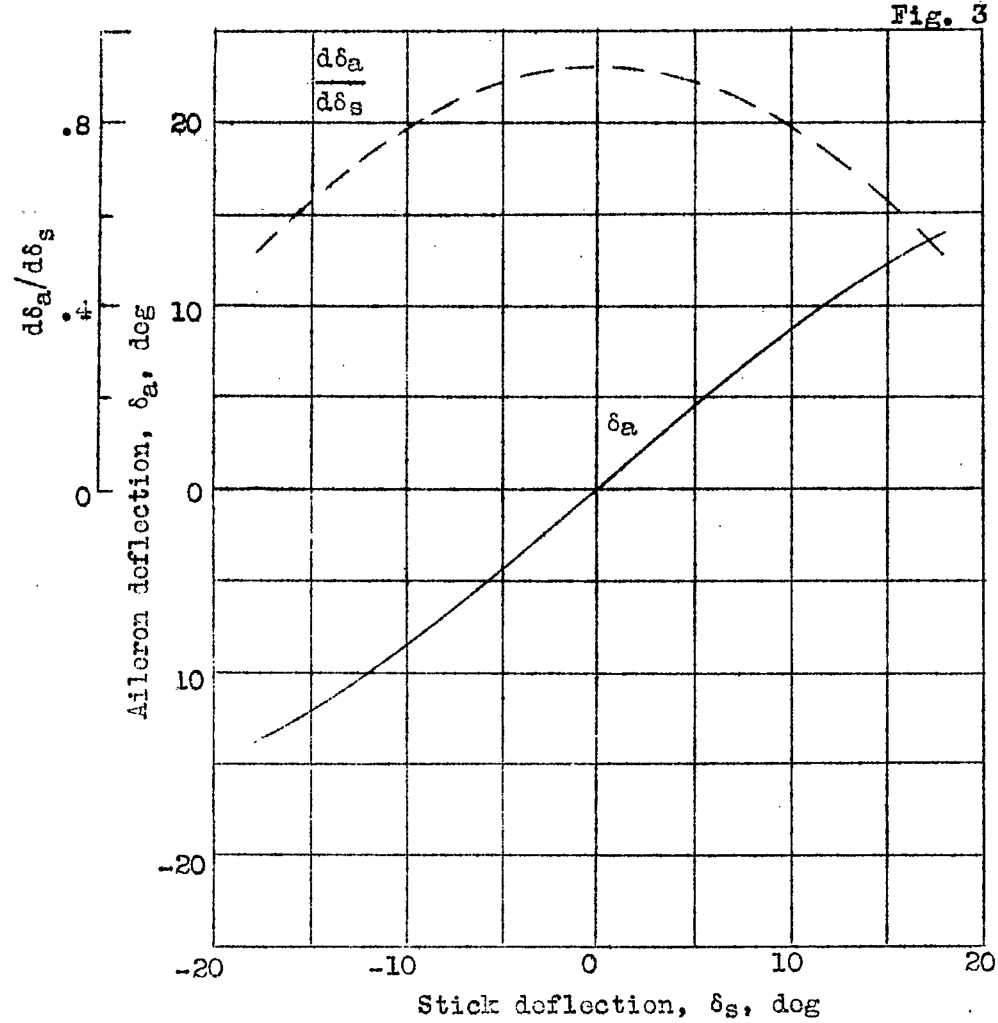


Figure 3.- Aileron-stick characteristics for sine linkage.





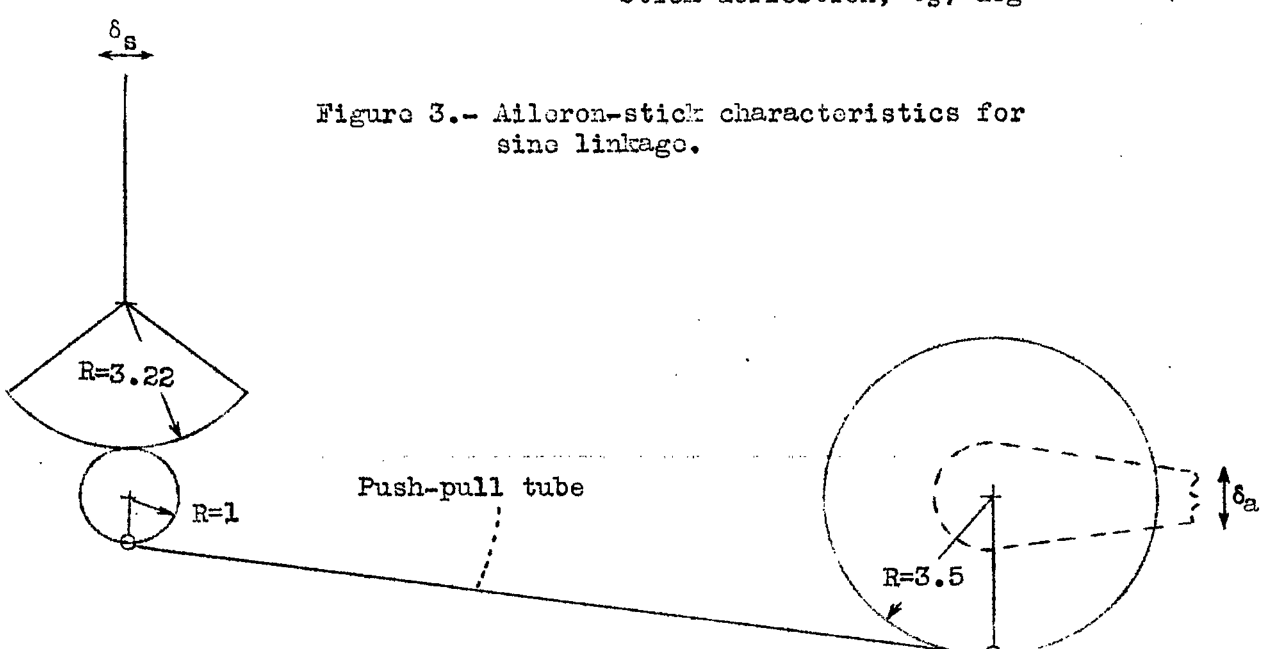


Figure 3.- Aileron-stick characteristics for sine linkage.

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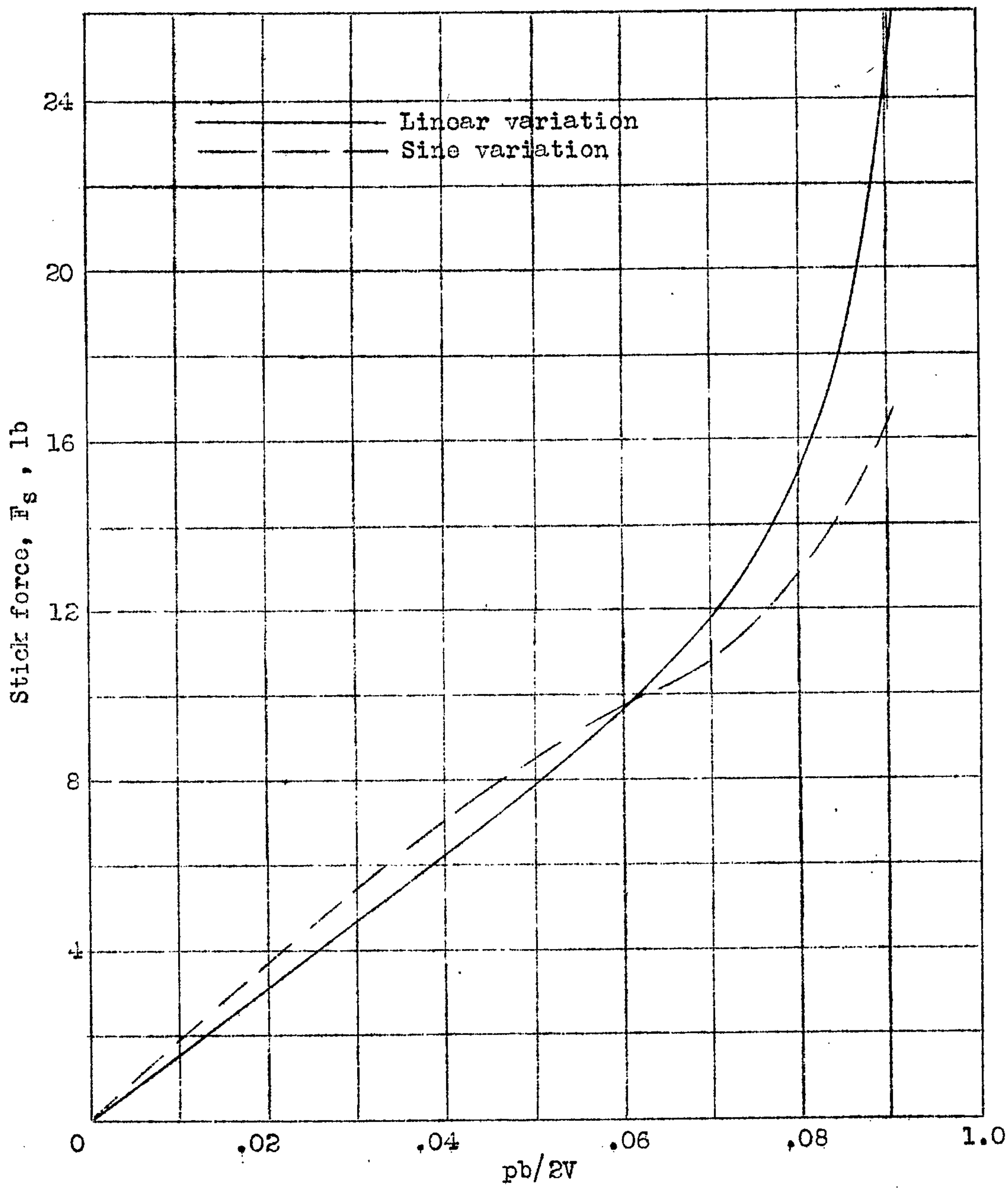

Figure 4.- The effect of aileron-stick linkage on stick force.