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RESEARCH MEMORANDUM

NOTES ON GEARED TABS AT SUPERSONIC SPEEDS

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SUMMARY

By use of the linearized theory, an analysis was made of the two-dimensional, geared, trailing-edge flap-tab combination at supersonic speeds to determine if, as at subsonic speeds, this combination could be used to reduce the hinge moments to extremely small values while retaining a large part of the lift effectiveness of a plain flap having the same ratio of flap chord to wing chord.

The analysis indicated that the behavior of the two-dimensional geared tab arrangement at supersonic speeds is by no means as excellent as it is at subsonic speeds. If the combination is designed to give zero hinge moment due to control deflection, then the lift effectiveness will also be zero. In order to produce a given lift, the geared flap arrangement would require less pilot effort than would a plain flap having the same flap-chord ratio, but the performance of the geared arrangement could be equalled by a smaller-chord plain flap. It was shown that the only advantage the geared flap arrangement possessed over the small-chord plain flap was the possibility of controlling the hinge moment due to angle of attack.

A short analysis of the two-dimensional, geared, leading-edge and trailing-edge flap combination is also included.

INTRODUCTION

One of the more interesting of the control-surface configurations that have been investigated at subsonic speeds is the geared, trailing-edge flap-tab combination. In reference 1 it was shown theoretically that by a proper choice of gearing ratio this combination could give nearly complete hinge-moment balance with a relatively high lift effectiveness. This theoretical analysis was substantiated by an experimental investigation at a low speed (reference 2). There is other evidence, including flight-test data, to show that geared tabs are effective through a wide range of subsonic speeds.

Because of the apparent excellence of the geared flap control at subsonic speeds, it was thought worth while to investigate its characteristics at supersonic speeds. To this end, the analysis of the present paper was made. For simplicity, the analysis was made for a two-dimensional thin-flat-plate wing-flap combination by use of the linearized theory.

The general equations for the geared trailing-edge flap combination also hold for the geared leading-edge and trailing-edge flap combination. This arrangement is currently being considered as a possible control for supersonic speeds; therefore, a brief analysis of this case was also included.

SYMBOLS

c	airfoil chord
c_f	flap chord (see figs. 1 and 3)
c_t	tab chord (see figs. 1 and 3)
c_h	hinge-moment coefficient of geared flap-tab combination $\left(\frac{h}{qc_f^2}\right)$
c_{h_f}	hinge-moment coefficient of flap $\left(\frac{h_f}{qc_f^2}\right)$
c_{h_t}	hinge-moment coefficient of tab $\left(\frac{h_t}{qc_t^2}\right)$
h	hinge moment of geared flap-tab combination about flap hinge line (see figs. 1 and 3)
h_f	hinge moment about flap hinge line when tab is not geared but can be moved independently of flap (see figs. 1 and 3)
h_t	hinge moment of tab about tab hinge line (see figs. 1 and 3)
M	Mach number
q	dynamic pressure
α	angle of attack, radians
$\beta = \sqrt{M^2 - 1}$	
δ_f	flap deflection, radians (see figs. 1 and 3)
δ_t	tab deflection, radians (see figs. 1 and 3)

ANALYSIS AND DISCUSSION

Geared trailing-edge flaps.- The control-surface configuration, consisting of two serially hinged flaps located at the wing trailing edge and geared to move at a certain rate $\partial\delta_t/\partial\delta_f$ with respect to each other, is shown in figure 1. For convenience, the larger of the two surfaces will be called the flap; the smaller, the tab. This is the arrangement investigated theoretically in reference 1 and experimentally in reference 2 (for low subsonic speeds). For either the subsonic case or the supersonic case, the following equations apply:

$$\frac{dc_h}{d\delta_f} = \frac{\partial c_{h_f}}{\partial\delta_f} + \left(\frac{c_t}{c_f}\right)^2 \frac{\partial\delta_t}{\partial\delta_f}\left(\frac{\partial c_{h_t}}{\partial\delta_t}\frac{\partial\delta_t}{\partial\delta_f} + \frac{\partial c_{h_t}}{\partial\delta_f}\right) + \frac{\partial c_{h_f}}{\partial\delta_t}\frac{\partial\delta_t}{\partial\delta_f} \tag{1}$$

$$\frac{dc_h}{d\alpha} = \frac{\partial c_{h_f}}{\partial\alpha} + \left(\frac{c_t}{c_f}\right)^2 \frac{\partial\delta_t}{\partial\delta_f}\frac{\partial c_{h_t}}{\partial\alpha} \tag{2}$$

$$\frac{d\alpha}{d\delta_f} = \frac{\partial\alpha}{\partial\delta_f} + \frac{\partial\alpha}{\partial\delta_t}\frac{\partial\delta_t}{\partial\delta_f} \tag{3}$$

The various parameters required in these equations for the supersonic case are easily found from the linearized theory for supersonic flow after the manner of reference 3, and are listed on the following page:

$$\left.\begin{aligned}
\frac{\partial c_{h_f}}{\partial \delta_f} &= -\frac{2}{\beta} \\
\frac{\partial c_{h_t}}{\partial \delta_t} &= -\frac{2}{\beta} \\
\frac{\partial c_{h_t}}{\partial \delta_f} &= -\frac{2}{\beta} \\
\frac{\partial c_{h_f}}{\partial \delta_t} &= -\frac{2}{\beta}\left[2\frac{c_t}{c_f} - \left(\frac{c_t}{c_f}\right)^2\right] \\
\frac{\partial c_{h_f}}{\partial \alpha} &= -\frac{2}{\beta} \\
\frac{\partial c_{h_t}}{\partial \alpha} &= -\frac{2}{\beta} \\
\frac{\partial \alpha}{\partial \delta_f} &= \frac{c_f}{c} \\
\frac{\partial \alpha}{\partial \delta_t} &= \frac{c_t}{c}
\end{aligned}\right\} \tag{4}$$

If these expressions are substituted in equations (1), (2), and (3), then one obtains

$$\frac{dc_h}{d\delta_f} = -\frac{2}{\beta}\left(1 + \frac{c_t}{c_f}\frac{\partial \delta_t}{\partial \delta_f}\right)^2 \tag{5}$$

$$\frac{dc_h}{d\alpha} = -\frac{2}{\beta}\left[1 + \left(\frac{c_t}{c_f}\right)^2 \frac{\partial \delta_t}{\partial \delta_f}\right] \tag{6}$$

$$\frac{d\alpha}{d\delta_f} = \frac{c_f}{c}\left(1 + \frac{c_t}{c_f}\frac{\partial \delta_t}{\partial \delta_f}\right) \tag{7}$$

The present control-surface arrangement can be compared with a plain flap having the same flap-chord ratio by noting that for the plain flap

$$\left(\frac{dc_h}{d\delta_f}\right)_{pf} = -\frac{2}{\beta} \tag{8}$$

$$\left(\frac{dc_h}{d\alpha}\right)_{pf} = -\frac{2}{\beta} \tag{9}$$

$$\left(\frac{d\alpha}{d\delta_f}\right)_{pf} = \frac{c_f}{c} \tag{10}$$

so that

$$\frac{dc_h/d\delta_f}{\left(dc_h/d\delta_f\right)_{pf}} = \left(1 + \frac{c_t}{c_f}\frac{\partial\delta_t}{\partial\delta_f}\right)^2 \tag{11}$$

$$\frac{dc_h/d\alpha}{\left(dc_h/d\alpha\right)_{pf}} = \left[1 + \left(\frac{c_t}{c_f}\right)^2\frac{\partial\delta_t}{\partial\delta_f}\right] \tag{12}$$

$$\frac{d\alpha/d\delta_f}{\left(d\alpha/d\delta_f\right)_{pf}} = \left(1 + \frac{c_t}{c_f}\frac{\partial\delta_t}{\partial\delta_f}\right) \tag{13}$$

Equation (11) can be expressed in terms of either equation (12) or equation (13). Thus,

$$\frac{dc_h/d\delta_f}{\left(dc_h/d\delta_f\right)_{pf}} = \left[\frac{d\alpha/d\delta_f}{\left(d\alpha/d\delta_f\right)_{pf}}\right]^2 \tag{14}$$

$$\frac{dc_h/d\delta_f}{(dc_h/d\delta_f)_{pf}} = \frac{1}{(c_t/c_f)^2}\left[\frac{dc_h/d\alpha}{(dc_h/d\alpha)_{pf}} + \left(\frac{c_t}{c_f} - 1\right)\right]^2 \tag{15}$$

Equations (14) and (15) are plotted in figure 2. The upper branches of the curves for $\frac{dc_h/d\alpha}{(dc_h/d\alpha)_{pf}}$ are for the case in which the lift comes from the flap, and the tab is used for balance of hinge moments (ordinary balancing tab); the lower branches are for a linkage such that the flap is used for hinge-moment balance, and the tab produces the lift (lifting tab). Because the $d\alpha/d\delta_f$ curve is symmetrical for the two cases, only one branch is plotted.

It is evident from the curves of figure 2 that for a geared arrangement designed to produce a given reduction in $dc_h/d\delta_f$ (compared with a plain flap of the same size) there will be a fixed reduction in $d\alpha/d\delta_f$, but by selecting values of c_t/c_f and $\partial\delta_t/\partial\delta_f$ the value of $dc_h/d\alpha$ can be adjusted over a wide range.

It is noted that, if a geared arrangement is designed to give $\frac{dc_h}{d\delta_f} = 0$, then of necessity $\frac{d\alpha}{d\delta_f} = 0$ – obviously a not very practical control. This is the essential difference between the geared arrangement at low subsonic and supersonic speeds. (As noted in the "Introduction," for the subsonic case both $dc_h/d\delta_f$ and $dc_h/d\alpha$ could be made very close to zero with not too great a loss in $d\alpha/d\delta_f$.) This behavior of the geared-tab arrangement at supersonic speeds is perhaps more easily seen if it is postulated that the lift produced by deflection of the combination is zero. Then, within the limits of the linearized theory the trailing edge does not move vertically with respect to the chord line of the airfoil, and simple work considerations show that the work (and therefore the hinge moment) required to deflect the system is zero.

It can be shown that, in two-dimensional supersonic flow, for both the geared arrangement and for the plain flap the actual hinge moment (not hinge-moment coefficient) required to produce a given lift at a fixed angle of attack is directly proportional to $d\alpha/d\delta_f$. Consider, for example, three cases: a 0.50c plain flap, a 0.50c geared arrangement designed to have a $dc_h/d\delta_f$ one-quarter that of the 0.50c plain flap, and a 0.25c plain flap. Both the 0.50c geared arrangement and the 0.25c plain flap will have one-half the $d\alpha/d\delta_f$ of the 0.50c plain flap; therefore, to produce a given lift either arrangement will require only one-half the pilot effort that would be needed with the 0.50c plain flap. Thus, the only advantage a geared arrangement has over a small plain flap is the possibility of controlling $dc_h/d\alpha$.

There is no assurance that the behavior of the geared tab in a given three-dimensional case will be similar to that indicated by the preceding analysis of the two-dimensional case. For example, some preliminary calculations for a geared triangular-flap – triangular-tab combination on a triangular wing (using reference 3 to obtain the various parameters) indicated that the performance of this particular three-dimensional arrangement was even worse than indicated by the two-dimensional analysis. Of course, there is no reason that some other three-dimensional arrangement should not show better characteristics.

The effect of a finite airfoil thickness on the numerical values presented in figure 2 was briefly investigated by using the theoretical pressure-distribution data of reference 4. A double-wedge airfoil of 5.24-percent thickness (6° included angle) was used with a 0.50c flap and a $0.50c_f$ tab. The calculations were made for a Mach number of 2.0. The results indicated that for the conventional balancing tab arrangement the effect of airfoil thickness on the lift and hinge-moment characteristics was negligible. For the lifting tab arrangement, however, a loss of about 15 percent in lift effectiveness was obtained with little effect on the hinge-moment characteristics.

Geared leading-edge and trailing-edge flaps.– Equations (1), (2), and (3) can be shown to apply also to the geared leading-edge and trailing-edge flap arrangement shown in figure 3. The parameters for this case are listed below:

$$\left.\begin{aligned}
\frac{\partial c_{h_f}}{\partial \delta_f} &= -\frac{2}{\beta} \\
\frac{\partial c_{h_t}}{\partial \delta_t} &= \frac{2}{\beta} \\
\frac{\partial c_{h_t}}{\partial \delta_f} &= 0 \\
\frac{\partial c_{h_f}}{\partial \delta_t} &= 0 \\
\frac{\partial c_{h_f}}{\partial \alpha} &= -\frac{2}{\beta} \\
\frac{\partial c_{h_t}}{\partial \alpha} &= \frac{2}{\beta} \\
\frac{\partial \alpha}{\partial \delta_f} &= \frac{c_f}{c} \\
\frac{\partial \alpha}{\partial \delta_t} &= \frac{c_t}{c}
\end{aligned}\right\} \qquad (16)$$

Following the same procedure as for the preceding analysis, there results

$$\frac{dc_h/d\delta_f}{\left(dc_h/d\delta_f\right)_{pf}} = 1 - \left(\frac{c_t}{c_f}\right)^2 \left(\frac{\partial\delta_t}{\partial\delta_f}\right)^2 \tag{17}$$

$$\frac{dc_h/d\alpha}{\left(dc_h/d\alpha\right)_{pf}} = 1 - \left(\frac{c_t}{c_f}\right)^2 \frac{\partial\delta_t}{\partial\delta_f} \tag{18}$$

$$\frac{d\alpha/d\delta_f}{\left(d\alpha/d\delta_f\right)_{pf}} = 1 + \frac{c_t}{c_f}\frac{\partial\delta_t}{\partial\delta_f} \tag{19}$$

and

$$\frac{dc_h/d\delta_f}{\left(dc_h/d\delta_f\right)_{pf}} = 1 - \left[\frac{d\alpha/d\delta_f}{\left(d\alpha/d\delta_f\right)_{pf}} - 1\right]^2 \tag{20}$$

$$\frac{dc_h/d\delta_f}{\left(dc_h/d\delta_f\right)_{pf}} = 1 - \frac{1}{\left(c_t/c_f\right)^2}\left[1 - \frac{dc_h/d\alpha}{\left(dc_h/d\alpha\right)_{pf}}\right]^2 \tag{21}$$

Equations (20) and (21) are plotted in figure 4. It is important to note that the lower branches of the curves for $\frac{dc_h/d\alpha}{\left(dc_h/d\alpha\right)_{pf}}$ correspond to the upper branch of the curve for $\frac{d\alpha/d\delta_f}{\left(d\alpha/d\delta_f\right)_{pf}}$ and conversely.

The curves of figure 4 show that for $\frac{c_t}{c_f} = 1$ both $dc_h/d\delta_f$ and $dc_h/d\alpha$ can be made zero, and the lift effectiveness will be equal to that of a plain trailing-edge flap having an area equal to the combined areas of the flap and tab. Again, it is pointed out that there will be important three-dimensional effects for many cases.

CONCLUDING REMARKS

For flow at subsonic speeds, it has previously been shown that a geared trailing-edge flap arrangement can be designed to give both $dc_h/d\delta_f$ and $dc_h/d\alpha$ very near to zero, with a relatively small loss in $d\alpha/d\delta_f$ compared with a plain flap of the same chord. The present analysis of the two-dimensional geared flap arrangement in supersonic flow (based on the linearized theory) indicates that, if $dc_h/d\delta_f$ is made zero, then $d\alpha/d\delta_f$ will also be zero. The only advantage of the geared arrangement over a small-chord plain flap is that for the geared flap the parameter $dc_h/d\alpha$ can be controlled within wide limits. Of course, three-dimensional effects may either improve or worsen the behavior indicated by the analysis of the two-dimensional case.

The corresponding analysis for the two-dimensional, geared, leading-edge and trailing-edge flap arrangement in supersonic flow indicates that, if the leading-edge and trailing-edge flaps have the same chord, both $dc_h/d\delta_f$ and $dc_h/d\alpha$ can be made zero, with the lift effectiveness equal to that of a plain trailing-edge flap having a chord equal to the sum of the chords of the leading-edge and trailing-edge flaps. For this arrangement, too, three-dimensional effects must be considered.

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REFERENCES

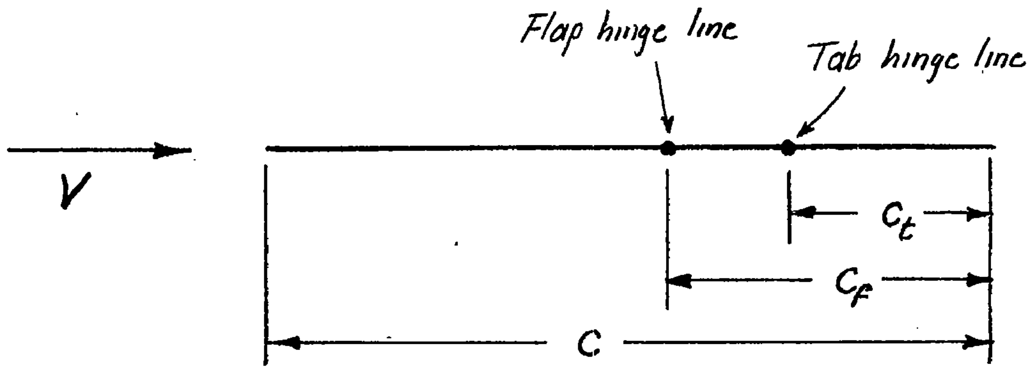
1. Sears, Richard I.: Wind-Tunnel Data on the Aerodynamic Characteristics of Airplane Control Surfaces. NACA ACR No. 3L08, 1943.

2. Spearman, M. Leroy: Wind-Tunnel Investigation of Control-Surface Characteristics. XXIII – A 0.25-Airfoil-Chord Flap with Tab Having a Chord Twice the Flap Chord on an NACA 0009 Airfoil. NACA ARR No. L5G25, 1945.

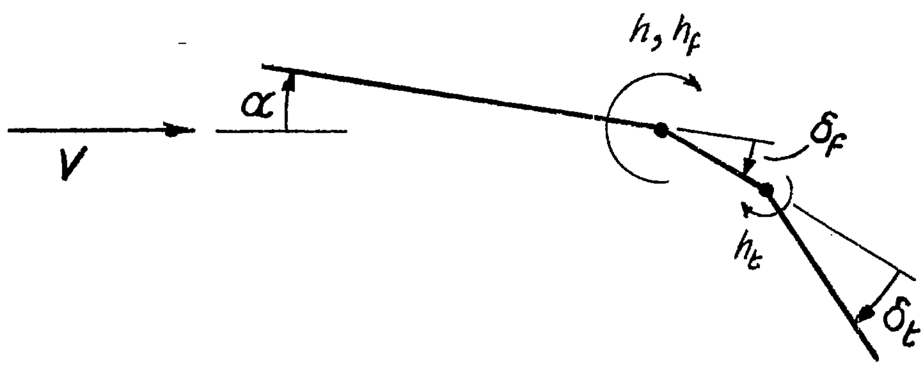
3. Collar, A. R.: Theoretical Forces and Moments on a Thin Aerofoil with Hinged Flap at Supersonic Speeds. R. & M. No. 2004, British A.R.C., 1943.

4. Tucker, Warren A.: Characteristics of Thin Triangular Wings with Triangular-Tip Control Surfaces at Supersonic Speeds with Mach Lines behind the Leading Edge. NACA TN No. 1600, 1947.

5. Ivey, H. Reese: Notes on the Theoretical Characteristics of Two-Dimensional Supersonic Airfoils. NACA TN No. 1179, 1947.



(a) Dimension notation.



(b) Deflection notation.

Figure 1.- Two-dimensional, geared, trailing-edge flap-tab combination.

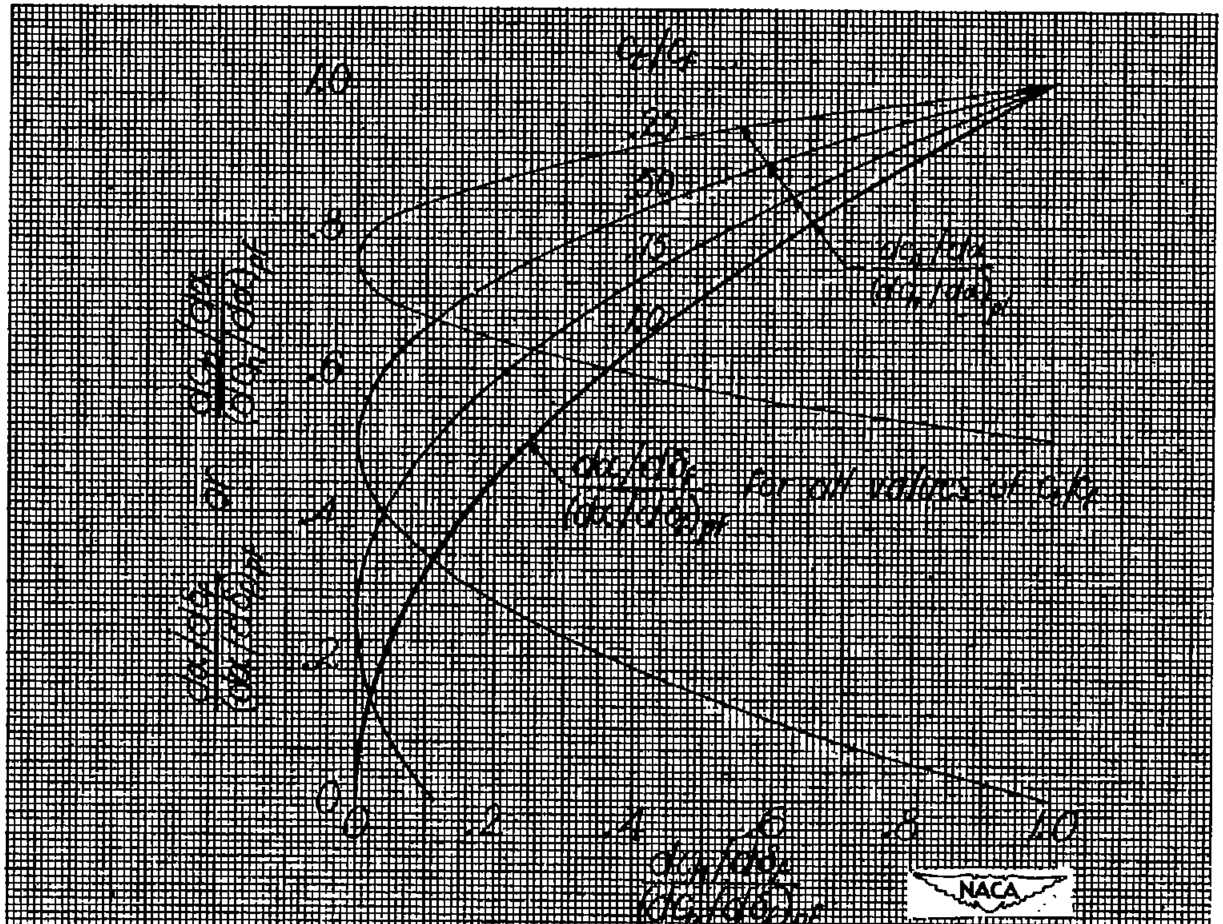
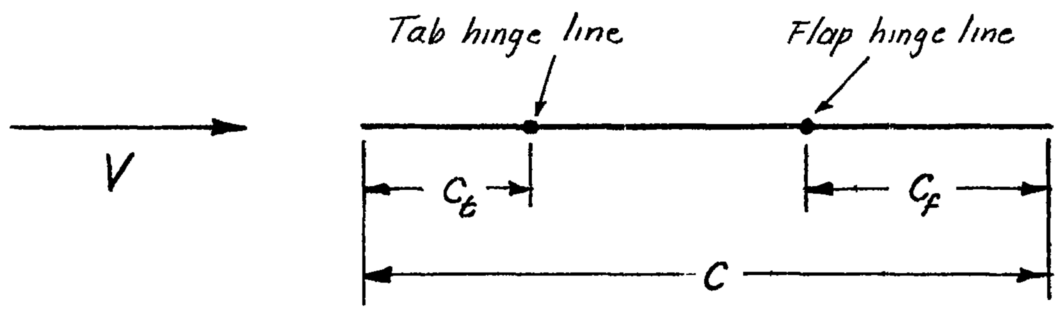
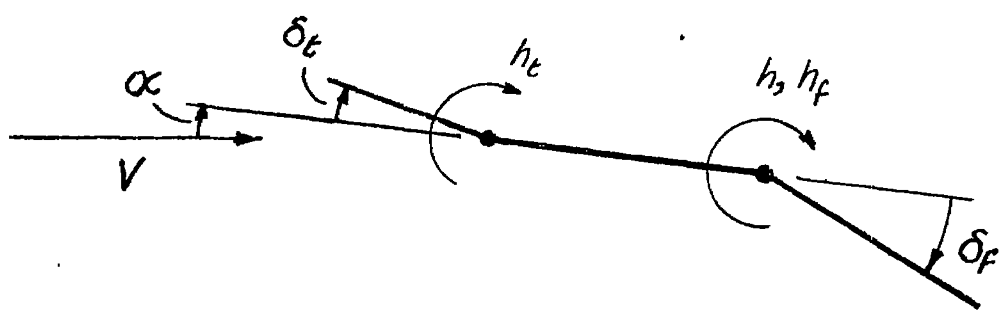


Figure 2.– Comparison of geared trailing-edge flap-tab combination with plain flap having the same flap-chord ratio.



(a) Dimension notation.



(b) Deflection notation.

Figure 3.- Two-dimensional geared, leading- and trailing-edge flap combination.

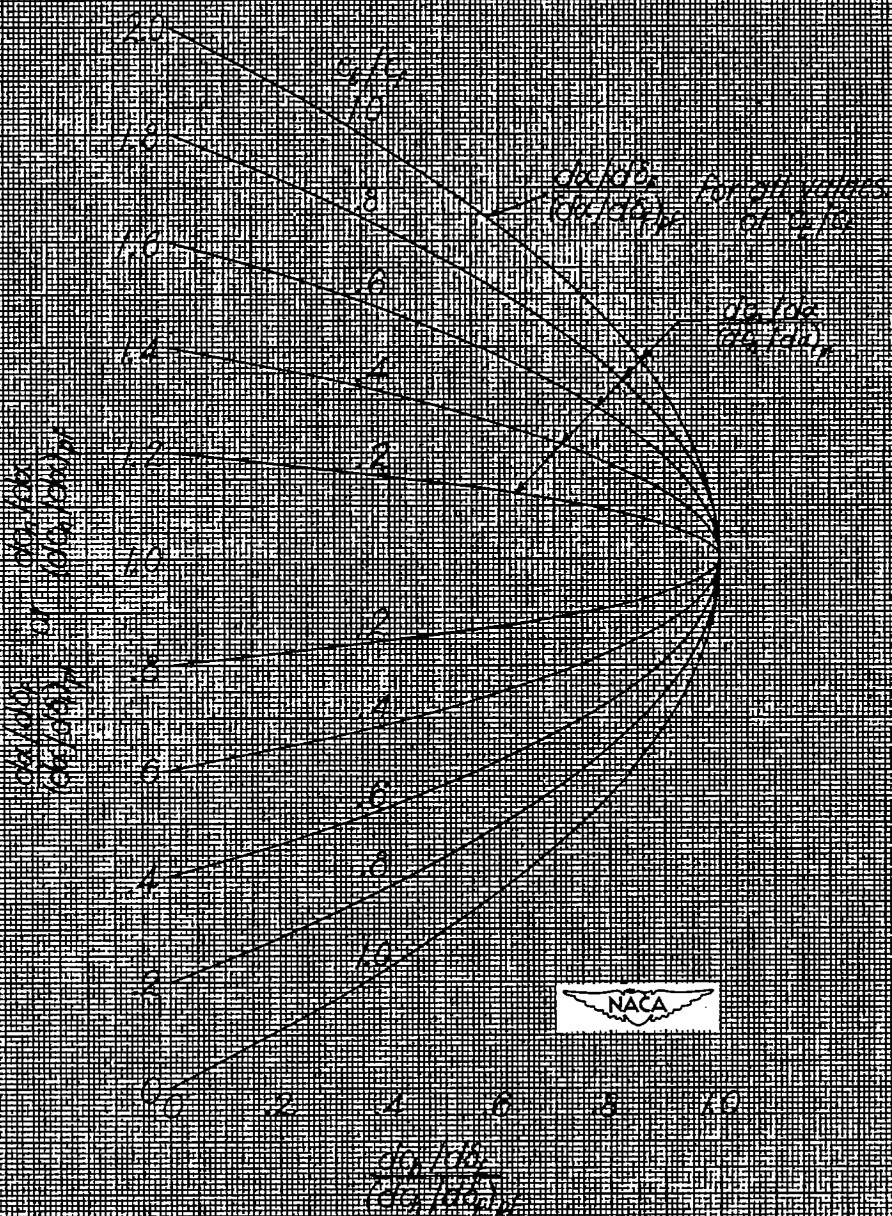


Figure 4.- Comparison of geared leading- and trailing-edge flap combination with plain flap having the same flap-chord ratio.