Library Copy
R.A. 1505

Copy 23
RM SL50E01

[redacted]

[redacted]

NACA

RESEARCH MEMORANDUM

for the

Air Materiel Command, U. S. Air Force

STATIC LONGITUDINAL STABILITY OF A TANDEM-COUPLED BOMBER-FIGHTER AIRPLANE CONFIGURATION SIMILAR TO ONE PROPOSED BY DOUGLAS AIRCRAFT COMPANY, INC.

By Donald E. Hewes

Langley Aeronautical Laboratory
Langley Air Force Base, Va.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

Apr 28 1950

[redacted]

[redacted]

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

for the

Air Materiel Command, U. S. Air Force

STATIC LONGITUDINAL STABILITY OF A TANDEM-COUPLED BOMBER-FIGHTER AIRPLANE CONFIGURATION SIMILAR TO ONE PROPOSED BY DOUGLAS AIRCRAFT COMPANY, INC.

By Donald E. Hewes

SUMMARY

At the request of the Air Materiel Command, an investigation was made in the Langley free-flight tunnel to determine the longitudinal stability and control characteristics of models coupled together in a tandem configuration for aerial refueling similar to one proposed by the Douglas Aircraft Company, Inc. Static force tests were made with $\frac{1}{20}$-scale models of the B-29 and F-80 airplanes to determine the effects of rigidly coupling the airplanes together. The Douglas configuration differs from the rigid configuration tested in that it provides for some freedom in pitch and vertical displacement.

The force tests showed that, for the bomber alone, the aerodynamic center was 0.21 mean aerodynamic chord behind the center of gravity (stable) but that for the tandem configuration with rigid coupling the aerodynamic center was 0.28 mean aerodynamic chord forward of the center of gravity of the combination (unstable). This reduction in stability was caused by the downwash of the bomber on the fighter. The pitching moment produced by elevator deflection of the bomber was reduced approximately 50 percent by addition of the fighter. Some recent flight tests made in the free-flight tunnel on models in a similar tandem configuration indicated that, with a hinged coupling permitting freedom in pitch, the stability of the combination was better than that obtained with a rigid coupling and was about the same as that for the bomber alone.

INTRODUCTION

At the request of the Air Materiel Command, an investigation was made in the Langley free-flight tunnel to determine the longitudinal stability and control characteristics of models coupled together in a tandem configuration for aerial refueling similar to that proposed by the Douglas Aircraft Company, Inc. Static force tests were made with $\frac{1}{20}$-scale models of the B-29 and F-80 airplanes to determine the effects of rigidly coupling the airplanes together. The Douglas configuration differs from the rigid configuration tested in that it provides for some freedom in pitch and vertical displacement. The effect of this difference in the restraint provided by the coupling was estimated from the results of previous flight tests of coupled airplane models in the Langley free-flight tunnel.

SYMBOLS

S	wing area, square feet
$\bar{c}$	wing mean aerodynamic chord, feet
l	tail length, distance from center of gravity to quarter root-chord station of horizontal tail, feet
m	distance from center of gravity of the bomber alone to center of gravity of the bomber-fighter combination, feet
n	distance from center of gravity of the bomber-fighter combination to center of gravity of fighter, feet
V	airspeed, feet per second
ρ	air density, slugs per cubic foot
q	dynamic pressure, pounds per square foot $\left(\frac{\rho}{2} V^2\right)$
α	angle of attack of reference axis, degrees
ε	downwash angle, degrees
δ_e	angle of elevator deflection, positive downward, degrees
C_L	lift coefficient (Lift/qS)

C_m pitching-moment coefficient about airplane center of gravity (Pitching moment/$qS\bar{c}$)

C_{L_α} rate of change of lift coefficient with angle of attack, per degree $(\partial C_L/\partial \alpha)$

C_{m_α} rate of change of pitching-moment coefficient with angle of attack, per degree $(\partial C_m/\partial \alpha)$

$C_{m_{\delta_e}}$ elevator effectiveness, rate of change of pitching-moment coefficient with elevator deflection, per degree $(\partial C_m/\partial \delta_e)$

$\frac{d\varepsilon}{d\alpha}$ rate of change of downwash angle with angle of attack, per degree

Subscripts:

b bomber, B-29

f fighter, F-80

w wing

t horizontal tail

APPARATUS

The investigation was made in the Langley free-flight tunnel which is described in references 1 and 2.

A three-view drawing of the models used in the investigation is shown in figure 1 and the physical characteristics are listed in table I. The weights of the full-scale airplanes were assumed to be 140,000 and 15,300 pounds for the bomber and fighter, respectively. The center of gravity of each model was assumed to be located at 0.26 mean aerodynamic chord and the resulting center of gravity of the combination was at 0.92 mean aerodynamic chord of the bomber. The F-80 model represented approximately a scale model of the F-80 prototype. The F-80 model was coupled rigidly to the B-29 model by four adjustable arms which maintained the same relative positions between the models as the Douglas coupling. The Douglas coupling incorporates ball-socket joints at the ends of the parallelogram linkage which permit freedom in vertical displacement. It also has shock units in the linkage arms which permit a certain amount of freedom in pitch. These details were not duplicated on the model, however, since they were obviously unnecessary for this investigation of the rigid condition.

FORCE TESTS

The lift, drag, and pitching moment of the B-29 model with the horizontal tail on and off, of the F-80 model alone, and of the combination were measured through an angle-of attack range of -2° to 8°. Tests of the combination were made with the F-80 model in two positions relative to the B-29 model: (1) directly behind at the same geometric angle of attack as the bomber, and (2) behind and above the horizontal tail (coupling linkage deflected 15°) at the same geometric angle of attack as the bomber (fig. 1). Elevator control effectiveness of the B-29 was measured for both the coupled and uncoupled conditions. Elevator settings of $\pm 5^{\circ}$ were used. All coefficients for the coupled condition are based on the wing area and mean aerodynamic chord of the B-29 and are referred to the center of gravity of the combination.

CALCULATIONS

The downwash factor for each surface was calculated by comparing the pitching-moment coefficient about the airplane center of gravity produced by the surface while in the downwash field with the pitching-moment coefficient produced by the same surface when isolated from the downwash field.

The downwash factor $\left(1 - \frac{d\varepsilon}{d\alpha}\right)_{wb}$ at the tail of the bomber due to the bomber wing was calculated from the force-test data for the bomber alone by the following approximate equation:

$$\left(1 - \frac{d\varepsilon}{d\alpha}\right)_{wb} \approx - \frac{\left(C_{m_\alpha}\right)_{\text{Tail on}} - \left(C_{m_\alpha}\right)_{\text{Tail off}}}{\left(C_{L_\alpha}\right)_{\text{Tail}}\left(\frac{l}{c}\right)\left(\frac{S_{b_t}}{S_{b_w}}\right)} \tag{1}$$

where $\left(C_{m_\alpha}\right)_{\text{Tail on}}$ and $\left(C_{m_\alpha}\right)_{\text{Tail off}}$ are based on the wing area of the bomber. The term $\left(C_{L_\alpha}\right)_{\text{Tail}}$ is the lift-curve slope for the tail when not in the downwash field of the wing and is based on the tail area.

The total downwash factor $\left(1 - \frac{d\varepsilon}{d\alpha}\right)_{wtb}$ due to the bomber wing and tail on the fighter wing was calculated by the following approximate equation:

$$\left(1 - \frac{d\varepsilon}{d\alpha}\right)_{wtb} \approx - \frac{\left(C_{m_\alpha}\right)_{bf} - \left(C_{m_\alpha}\right)_b - \left(C_{L_\alpha}\right)_b\left(\frac{m}{\bar{c}}\right)}{\left(C_{L_\alpha}\right)_f\left(\frac{n}{\bar{c}}\right)\left(\frac{S_{f_w}}{S_{b_w}}\right)} \tag{2}$$

where $\left(C_{m_\alpha}\right)_{bf}$ is based on the wing area and the mean aerodynamic chord of the bomber and the center of gravity of the combination.

In the determination of the contribution of the bomber tail to the total downwash factor at the fighter wing, the downwash due to the bomber wing was assumed to be the same at the fighter wing as at the bomber tail. Therefore,

$$\left(1 - \frac{d\varepsilon}{d\alpha}\right)_{tb} \approx \frac{\left(1 - \frac{d\varepsilon}{d\alpha}\right)_{wtb}}{\left(1 - \frac{d\varepsilon}{d\alpha}\right)_{wb}} \tag{3}$$

The error in this assumption is believed to be small since there is probably only a small gradient of $\left(1 - \frac{d\varepsilon}{d\alpha}\right)_{wb}$ over the distance between the bomber tail and fighter wing.

RESULTS AND DISCUSSION

The data obtained from force tests are given in figures 2 and 3, and the aerodynamic parameters measured from these data and the calculated downwash factors are listed in table II. Drag and pitching-moment data for the F-80 model were unreliable because of the small size of the model and low tunnel speed and, therefore, are not presented. The values listed in table II for dC_m/dC_L, C_{m_α}, and C_{L_α} were given for the linear portions of the curves (between 0° and 4° angle of attack) presented in figure 2.

The force tests showed that, for the bomber alone, the aerodynamic center was 0.21 mean aerodynamic chord behind the center of gravity (stable) but that for the tandem configuration with rigid coupling the aerodynamic center was 0.28 mean aerodynamic chord forward of the center of gravity of the combination (unstable). This reduction in stability produced by addition of the fighter to the bomber was attributed to the effect of downwash from the bomber on the fighter and resulted from a 0.66-mean-aerodynamic-chord rearward shift of the center of gravity and a 0.17-mean-aerodynamic-chord rearward shift of the aerodynamic center. The stability of the combination was approximately the same for the two positions of the F-80 tested.

The pitching moment produced by elevator deflection $C_{m_{\delta_e}}$ of the bomber was reduced approximately 50 percent by addition of the fighter. (See fig. 3.) The rearward shift of the center of gravity reduced the effective tail length only slightly and therefore had only a small effect on the elevator effectiveness. The reduction in elevator effectiveness was caused mainly by the action of downwash from the deflected elevator on the fighter wing tending to produce an aerodynamic moment opposite to that produced by the deflected elevator.

Since the force-test data were obtained with the rigid coupling, it cannot be applied directly to the actual configuration proposed by Douglas which incorporates a flexible coupling allowing freedom in pitch and vertical displacement. Some flight tests (the results of which are unpublished) recently conducted in the Langley free-flight tunnel with models in a similar tandem configuration were made to show the effect on longitudinal stability of introducing flexibility into the coupling. These tests showed that, for any center-of-gravity location, the longitudinal stability was improved by changing the rigid coupling to one freely hinged in pitch. In fact, for any given center-of-gravity location, the stability of the model with hinged coupling appeared to be about the same as for the bomber alone. On the other hand, with the rigid coupling, longitudinal instability was encountered over a fairly large range of center-of-gravity locations for which the bomber alone was stable. It appears therefore that the reduction in stability produced by the addition of the fighter to the bomber as indicated by the force-test data may be minimized by incorporating a hinged coupling permitting freedom in pitch. However, to obtain a satisfactory quantitative estimation of the stability of this system, a complete theoretical analysis and flight tests with the airplanes or dynamically scaled models will be required.

CONCLUSIONS

The results of the investigation of the static longitudinal stability of a tandem-coupled bomber-fighter airplane configuration similar to one proposed by the Douglas Aircraft Company, Inc., showed that, for the bomber alone, the aerodynamic center was 0.21 mean aerodynamic chord behind the center of gravity (stable) but that for the tandem configuration with rigid coupling the aerodynamic center was 0.28 mean aerodynamic chord forward of the center of gravity of the combination (unstable). This reduction in stability was caused by the downwash of the bomber on the fighter. The pitching moment produced by elevator deflection of the bomber was reduced approximately 50 percent by addition of the fighter. Some recent flight tests made in the Langley free-flight tunnel with models of bomber-fighter coupled airplane configurations indicated that with a hinged coupling permitting freedom in pitch, similar to that provided in the Douglas system, the stability of the combination was better than that obtained with a rigid coupling and was about the same as that for the bomber alone.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Air Force Base, Va.

Donald E. Hewes

Donald E. Hewes
Aeronautical Research Scientist

Approved: Thomas A. Harris
Thomas A. Harris
Chief of Stability Research Division

lc

REFERENCES

1. Shortal, Joseph A., and Osterhout, Clayton J.: Preliminary Stability and Control Tests in the NACA Free-Flight Wind Tunnel and Correlation with Full-Scale Flight Tests. NACA TN 810, 1941.

2. Shortal, Joseph A., and Draper, John W.: Free-Flight-Tunnel Investigation of the Effect of Fuselage Length and the Aspect Ratio and Size of the Vertical Tail on Lateral Stability and Control. NACA ARR 3D17, 1943.

3. Tosti, Louis P.: Low-Speed Static Stability and Damping-in-Roll Characteristics of Some Swept and Unswept Low-Aspect-Ratio Wings. NACA TN 1468, 1947.

TABLE I

PHYSICAL CHARACTERISTICS OF THE $\frac{1}{20}$ - SCALE B-29 AND F-80 MODELS

Distance between center of gravity of B-29 and F-80 when coupled, ft	4.23
Distance of center of gravity of coupled configuration behind center of gravity of B-29, ft	0.42

	B-29	F-80
Wing area, sq ft	4.35	0.59
Span, ft	7.07	1.95
Mean aerodynamic chord, ft	0.64	0.34
Center-of-gravity location, percent M.A.C.	26.0	26.0
Horizontal tail length, ft	2.44	0.73
Horizontal tail area, sq ft	0.83	0.105

TABLE II

AERODYNAMIC PARAMETERS OBTAINED FROM FORCE TESTS OF THE B-29 AND F-80

[A value of $\left(C_{L_\alpha}\right)_t$ of 0.072 for the bomber tail was estimated from data of reference 3.]

Configuration	C_{L_α}	$\left(C_{m_\alpha}\right)_{Tail\ off}$	$\left(C_{m_\alpha}\right)_{Tail\ on}$	$\frac{dC_m}{dC_L}$
B-29	0.113	0.010	-0.026	-0.21
F-80	0.089	-----	------	-----
Coupled B-29 and F-80	0.122	-----	------	0.28

CALCULATED DOWNWASH FACTORS

$$\left(1 - \frac{d\varepsilon}{d\alpha}\right)_{wb} = 0.70$$ (bomber wing on tail)

$$\left(1 - \frac{d\varepsilon}{d\alpha}\right)_{wtb} = 0.18$$ (bomber wing and tail on fighter wing)

$$\left(1 - \frac{d\varepsilon}{d\alpha}\right)_{tb} = 0.26$$ (bomber tail on fighter)

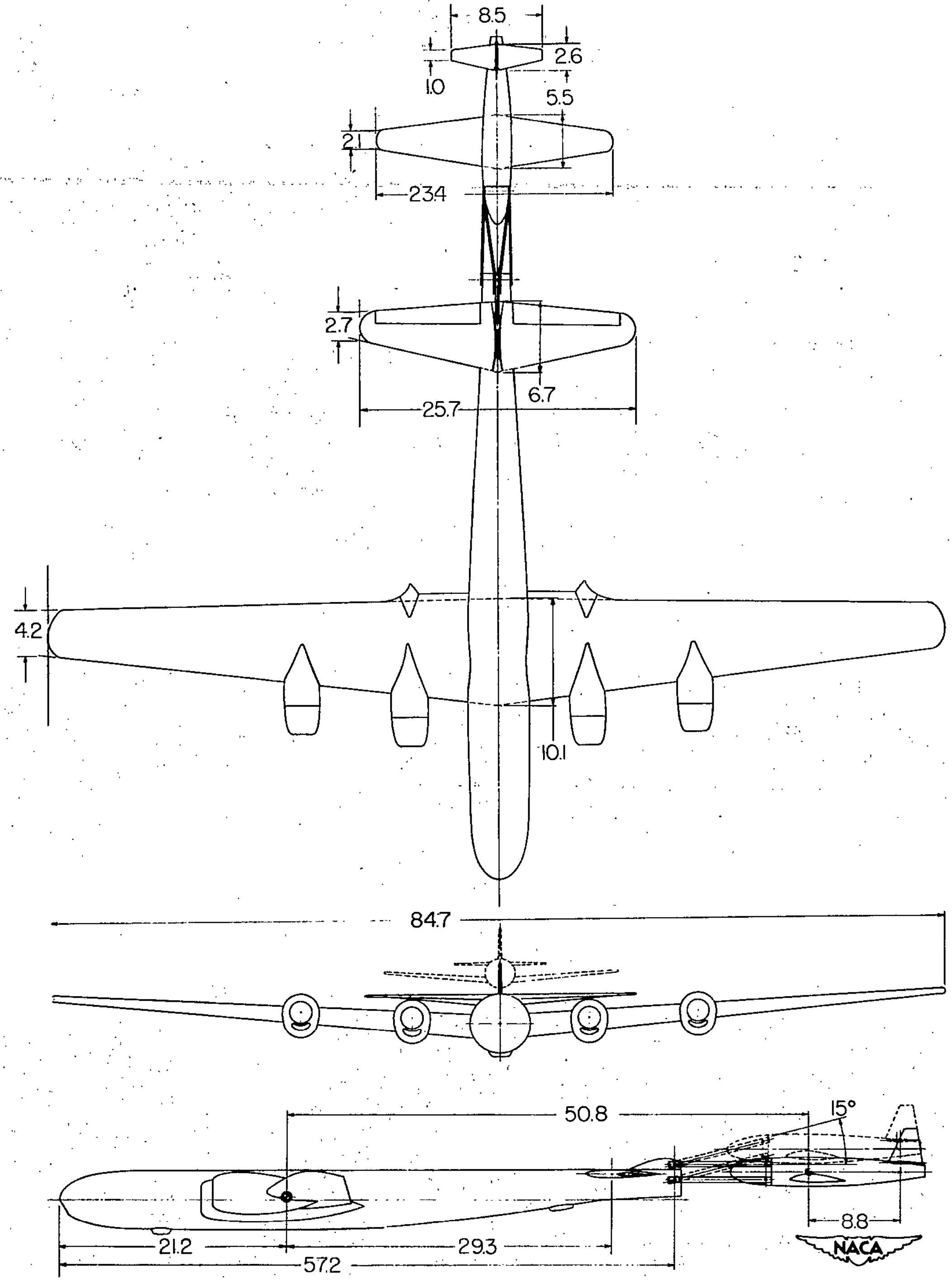

Figure 1.- Three-view drawing of the $\frac{1}{20}$- scale B-29 and F-80 models used for the investigation of a tandem-coupled bomber-fighter airplane configuration similar to that proposed by Douglas Aircraft Company. The two relative positions of the F-80 for the coupled configuration tested are shown. (All dimensions are in inches.)

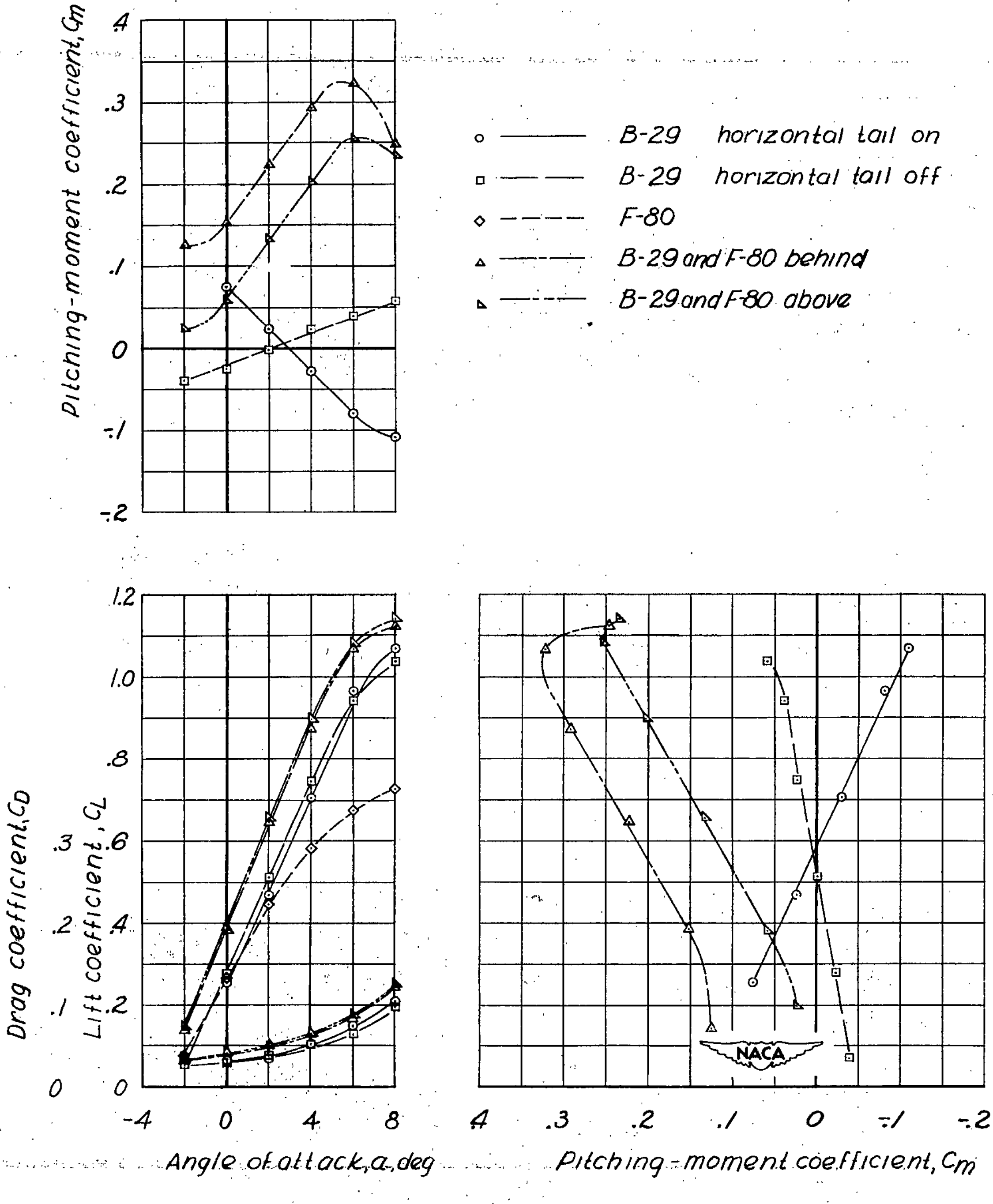

Figure 2.- Force-test data for the B-29 and F-80 models alone and for the coupled configuration. $\delta_e = 0^{\circ}$.

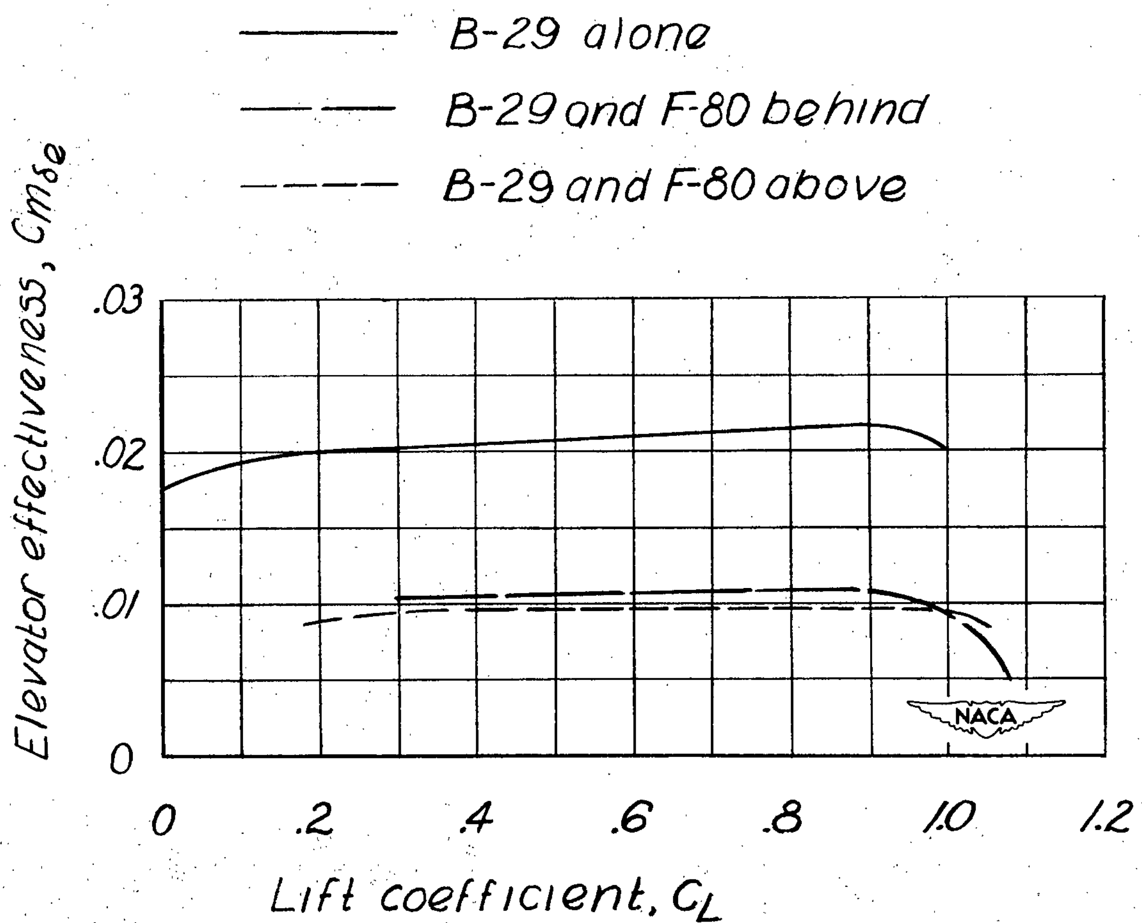

Figure 3.- Elevator effectiveness of the B-29 model for both the coupled and uncoupled conditions.