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RESEARCH MEMORANDUM

FREE-FLIGHT INVESTIGATION OF COMPARATIVE ZERO-LIFT ROLLING EFFECTIVENESS OF A LEADING-EDGE AND A TRAILING-EDGE AIR-JET SPOILER ON AN UNSWEPT WING

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

A free-flight investigation of the zero-lift rolling effectiveness of air-jet spoilers on an unswept flexible wing was conducted over a Mach number range of 0.7 to 1.9. The tests were made to determine the relative effectiveness of air-jet spoilers at leading-edge and trailing-edge locations.

The leading-edge jet spoiler exhibited near-zero effectiveness at transonic speeds and had a roll reversal between Mach numbers of 0.93 and 1.35. The trailing-edge jet spoiler was effective over the Mach number range covered. Of the two spoiler locations, the trailing-edge spoiler exhibited the greater effectiveness throughout the Mach number range covered, although, near the maximum Mach number, both spoiler locations had approximately the same rolling effectiveness.

INTRODUCTION

The Pilotless Aircraft Research Division has conducted a free-flight investigation to determine the zero-lift rolling effectiveness of air-jet spoilers on an unswept wing. Two models were flight tested, one with the spoiler located at 3.75 percent of the chord (leading edge) and the other with the spoiler located at 96.25 percent of the chord (trailing edge). The flight tests were conducted at the Pilotless Aircraft Research Station at Wallops Island, Va. and covered a Mach number range of 0.7 to 1.9 and a Reynolds number range of about 3 to 10×10^6.

The jet spoiler has an advantage over conventional controls in that low actuating forces are required. The jet spoiler may be used as a control irrespective of altitude since it provides jet reaction at very high altitudes and jet-plus-aerodynamic reaction at low altitudes. One disadvantage of jet spoilers is the ducting required, although duct requirements of the leading-edge jet spoiler in many cases may be more readily adaptable to conventional airfoils than that of a trailing-edge jet spoiler. At Mach numbers where leading-edge heating becomes a problem, the ducting and orifices of the leading-edge spoiler may be used for cooling purposes.

As with any type of spoiler, the chordwise location is important for maximum effectiveness. Most studies of spoilers of any type on unswept wings (such as ref. 1) have been conducted at chordwise locations well behind the leading edge. The trailing-edge air-jet spoiler has been found to be quite effective on two wing plan forms, a swept wing (ref. 2), and an 80° delta wing (ref. 3), whereas little or no data exist on the effectiveness of leading-edge air-jet spoilers.

SYMBOLS

A_j	total jet-exit cross-sectional area of one wing panel, sq ft
C_F	jet-thrust coefficient
C_{l_p}	damping-in-roll coefficient, $\frac{\text{Rolling moment}}{\left(\frac{pb}{2V}\right)qSb}$, per radian
F_j	jet force, lb
K	magnification factor, $\frac{\left(\frac{pb}{2V}\right)_{measured}}{\left(\frac{pb}{2V}\right)_{jet\ reaction}}$
M	Mach number
p_a	static free-stream pressure, lb/sq ft
p_t	stream stagnation pressure at inlet, lb/sq ft
R	Reynolds number based on mean aerodynamic chord

S	total wing-plan-form area taken to model center line, sq ft
V	flight-path velocity, ft/sec
b	wing span (diameter of circle passing through center line of jet intakes), ft
$\frac{b'}{2}$	exposed wing semispan, ft
c	wing chord, ft
p	rolling velocity, radians/sec
q	dynamic pressure, lb/sq ft
r	radius of nose section, in.
$\frac{\theta}{L}$	wing twist caused by a uniformly distributed load, radians/lb
x	longitudinal distance along model center line, in.
y	spanwise distance measured from wing-fuselage intersection, ft

MODELS

The general arrangement of the two models and details of the jet spoiler are shown in figure 1. Photographs of the models are shown in figure 2.

The two models were identical except for the jet-spoiler location; the jet spoiler was located near the leading edge at 3.75 percent of the chord on one model and near the trailing edge at 96.25 percent of the chord on the other. Each model had three identical magnesium wing panels spaced 120° apart around the fuselage at 0° incidence. The diamond airfoil section was 5 percent thick with 3/16-inch-radius rounded leading and trailing edge. A thin wooden overlay was cycle-welded to the magnesium wings to form a continuous surface with the sheet metal (1/16-inch steel) ducts. The wings were unswept and had a taper ratio of 1 and an aspect ratio of 2.72 based on the included area of two wing panels. The fuselage had an ogive nose (ordinates given in table I) and a cylindrical afterbody. The model weights were 46.0 pounds for the leading-edge spoiler and 45.2 pounds for the trailing-edge spoiler.

Each wing panel had an inlet which was a round steel tube, and the inlet area was 0.526 square inch. The jets were formed by 55 equally spaced holes 3/32 inch in diameter (see figs. 2(c) and 2(d)). The ratio of jet area to inlet area was 0.735.

FLIGHT-TESTING TECHNIQUE

The test measurements of zero-lift rolling effectiveness were obtained by the rocket-model technique and covered a Mach number range of 0.7 to 1.9. A single ABL Deacon rocket booster accelerated the model to the maximum Mach number. As the model decelerated through the Mach number range, measurements were made of the velocity by means of a CW Doppler velocimeter and of rolling velocity by means of spinsonde radio equipment. These data in conjunction with rawinsonde information and space coordinates, obtained with a modified SCR-584 radar unit, permitted an evaluation of the Mach number and the wing-tip helix angle as functions of time.

The test conditions for both models are shown in figure 3. Although the models were built to roll in a counterclockwise direction when viewed from the rear (negative roll direction), the values of the wing-tip helix angle are presented as positive if the model rolled in the direction intended. Negative values of $pb/2V$ indicated roll reversal.

ACCURACY AND CORRECTIONS

Calculations and flight experience on zero-lift models indicate that the experimental results are accurate to within the following limits:

	Subsonic	Supersonic
M	±0.01	±0.01
$\frac{pb}{2V}$, radians	±0.003	±0.002

Corrections to data for the wing-tip helix angle to account for small variations from 0° in wing incidence were found to be negligible. Inertia effects on the experimental values are believed to be negligible everywhere except in the regions where there are large changes in rolling velocity (near $M = 0.9$). In the region where the greatest changes in rolling velocity are experienced, the measured values may be in error by as much as 20 percent.

RESULTS AND DISCUSSION

Preflight

Prior to flight testing, one magnesium wing panel was tested to determine the degree of flexibility. The results of this test are presented in figure 4 as the spanwise variation of twist per pound due to a uniform load distributed along the leading-edge and trailing-edge jet positions, and the 25 percent and 75 percent chord lines. The elastic axis was found to be approximately the 50 percent chord line at all spanwise locations.

From the magnitude of the twist angle per pound, it may be noted that the wing cannot be considered rigid for model flight-test conditions; however, the data presented herein are uncorrected for aeroelastic effects. In order to determine aeroelastic corrections, knowledge of the chordwise and spanwise load distributions resulting from spoiling and aeroelasticity must be known. In the present investigation, corrections to the data for aeroelastic effects without pressure distributions and force tests are beyond the scope intended. It is believed, generally, that corrections to the data for aeroelastic effects would decrease the effectiveness of the leading-edge spoiler and increase the effectiveness of the trailing-edge spoiler.

Flight

The variation of the rolling effectiveness (wing-tip helix angle) of the leading-edge and trailing-edge spoiler is shown in figure 5 as a function of Mach number. Also included in this figure are the results from an investigation on the leading-edge and trailing-edge aileron of an unswept wing (ref. 4). The magnitudes of the rolling effectiveness from each investigation should not be compared since the aileron values are presented as rolling effectiveness per degree of aileron deflection. It may be noted, however, that the effectiveness of the leading-edge jet spoiler is quite similar to that of the leading-edge aileron of reference 4. The leading-edge jet spoiler has near-zero effectiveness at transonic speeds and exhibits a roll reversal between Mach numbers of 0.93 and 1.35. Throughout the Mach number range covered, the trailing-edge jet spoiler, like the trailing-edge aileron, exhibited greater effectiveness than the leading-edge spoiler or aileron, except near the maximum Mach number where both spoiler locations had approximately the same rolling effectiveness. The fact that the rolling effectiveness of the two spoiler locations was approximately the same at the maximum Mach number is probably due to the wing aeroelastic characteristics of the test models.

Presented in figure 6 is the variation of the estimated jet force per wing panel as a function of Mach number. The value of C_F was obtained from the test of reference 3 at approximately the same ratio of jet area to inlet area. The estimated jet force per wing panel varied with Mach number from about 1 pound at $M = 0.7$ to about 17 pounds at $M = 1.9$.

The variation of the rolling effectiveness of both spoiler locations and the rolling effectiveness caused by jet reaction alone as a function of Mach number is shown in figure 7. The rolling effectiveness of the jet reaction was obtained from the data of figure 6 and C_{l_p} of reference 5. At Mach numbers from 0.85 to 1.50, the leading-edge spoiler exhibited less rolling effectiveness than the jet reaction alone.

The magnification factor K presented as a function of Mach number in figure 8, was obtained by dividing the measured values of pb/2V for each spoiler location by the pb/2V value due to jet reaction alone. On rigid wings, a value of K of one indicates that all the rolling effectiveness is obtained from jet reaction and none from spoiling action. Negative values of K indicate roll in a direction opposite to that due to jet reaction. Over the Mach number range covered, the trailing-edge spoiler exhibited values of K greater than one. In the transonic speed region, the trailing-edge spoiler had 10 to 14 times the rolling effectiveness of that due to jet reaction alone. The leading-edge spoiler exhibited values of K less than ±2 over most of the Mach number range covered.

CONCLUDING REMARKS

The results of a free-flight investigation to determine the relative zero-lift roll effectiveness of leading-edge and trailing-edge air-jet spoiler location on a relatively flexible wing indicate the following concluding remarks. The leading-edge jet spoiler exhibited near-zero effectiveness in the transonic speed range and had a roll reversal between Mach numbers of 0.93 to 1.35. The trailing-edge jet spoiler was effective over the Mach number range covered. Of the two spoiler locations, the trailing-edge spoiler exhibited the greater effectiveness throughout the Mach number range covered, although near the maximum Mach number, both spoiler locations had approximately the same rolling effectiveness.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 20, 1957.

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1. Lord, Douglas R., and Czarnecki, K. R.: Pressure Distributions and Aerodynamic Characteristics of Several Spoiler-Type Controls on a Trapezoidal Wing at Mach Numbers of 1.61 and 2.01. NACA RM L56E22, 1956.

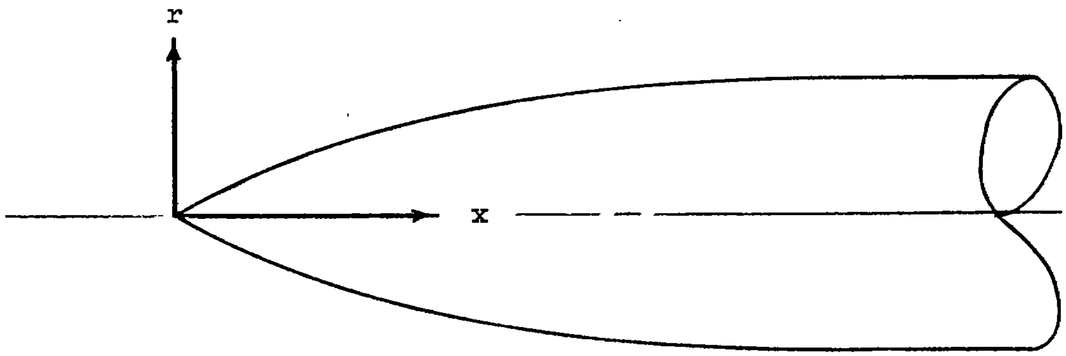
2. Lowry, John G.: Recent Control Studies. NACA RM L55L22a, 1956.

3. Schult, Eugene D.: Free-Flight Investigation at Mach Numbers Between 0.5 and 1.7 of the Zero-Lift Rolling Effectiveness and Drag of Various Surface, Spoiler, and Jet Controls on an 80° Delta-Wing Missile. NACA RM L56H29, 1956.

4. Strass, H. Kurt: Free-Flight Investigation of the Rolling Effectiveness at High Subsonic, Transonic, and Supersonic Speeds of Leading-Edge and Trailing-Edge Ailerons in Conjunction With Tapered and Untapered Plan Forms. NACA RM L8E10, 1948.

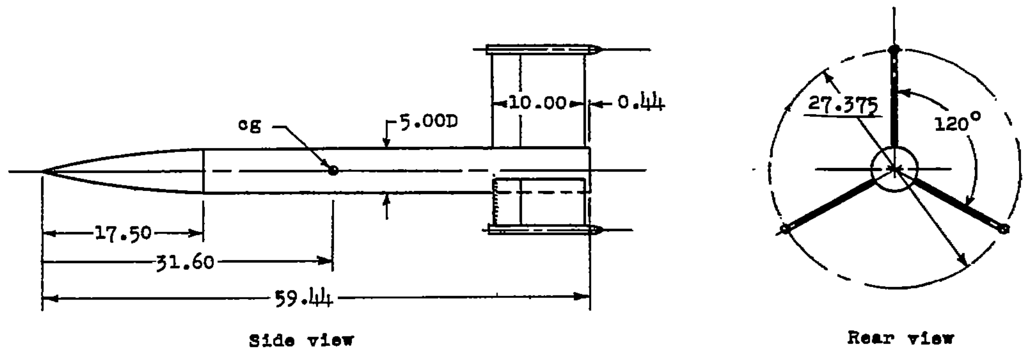
5. Bland, William M., Jr., and Dietz, Albert E.: Some Effects of Fuselage Interference, Wing Interference, and Sweepback on the Damping in Roll of Untapered Wings As Determined by Techniques Employing Rocket-Propelled Vehicles. NACA RM L51D25, 1951.

TABLE I

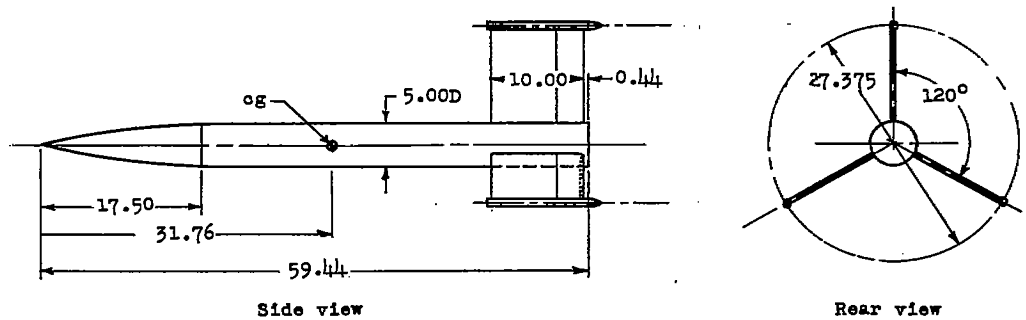


NOSE ORDINATES

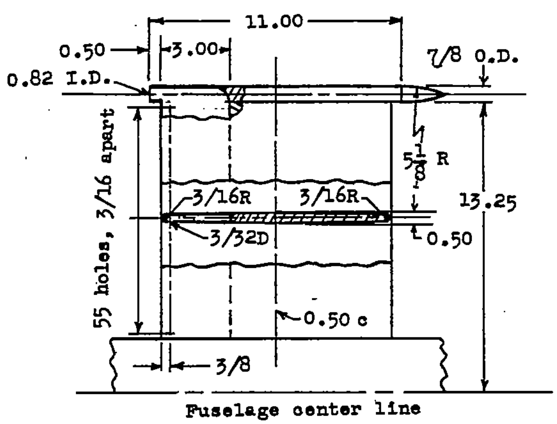
x, in.	r, in.
0	0
2.50	.590
5.00	1.150
7.50	1.570
10.00	1.995
12.50	2.252
15.00	2.429
17.50	2.500



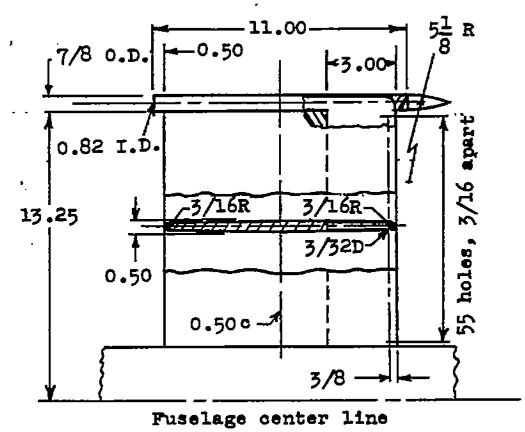
(a) Leading-edge jet-spoiler model.



(b) Trailing-edge jet-spoiler model.



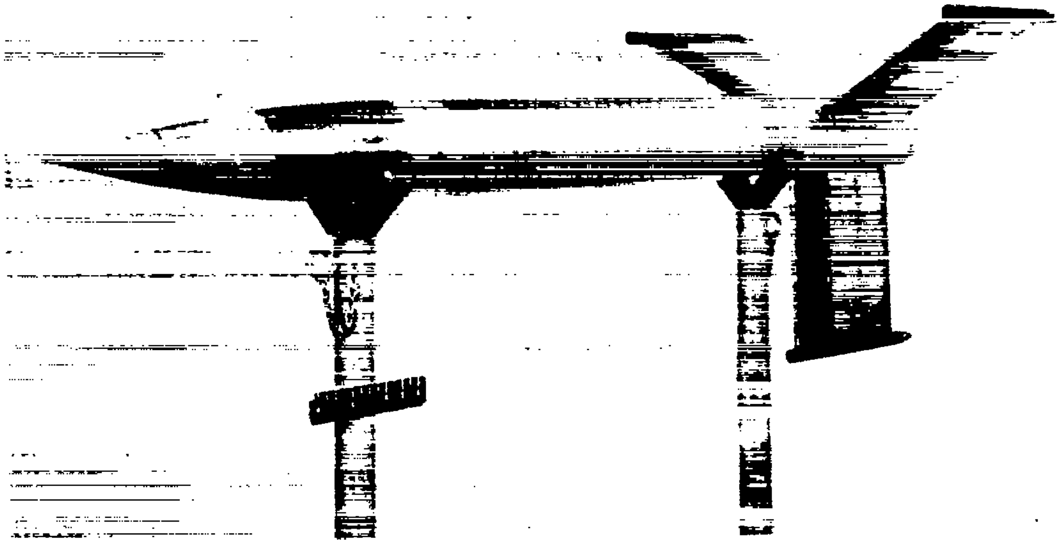
(c) Leading-edge jet-spoiler details.



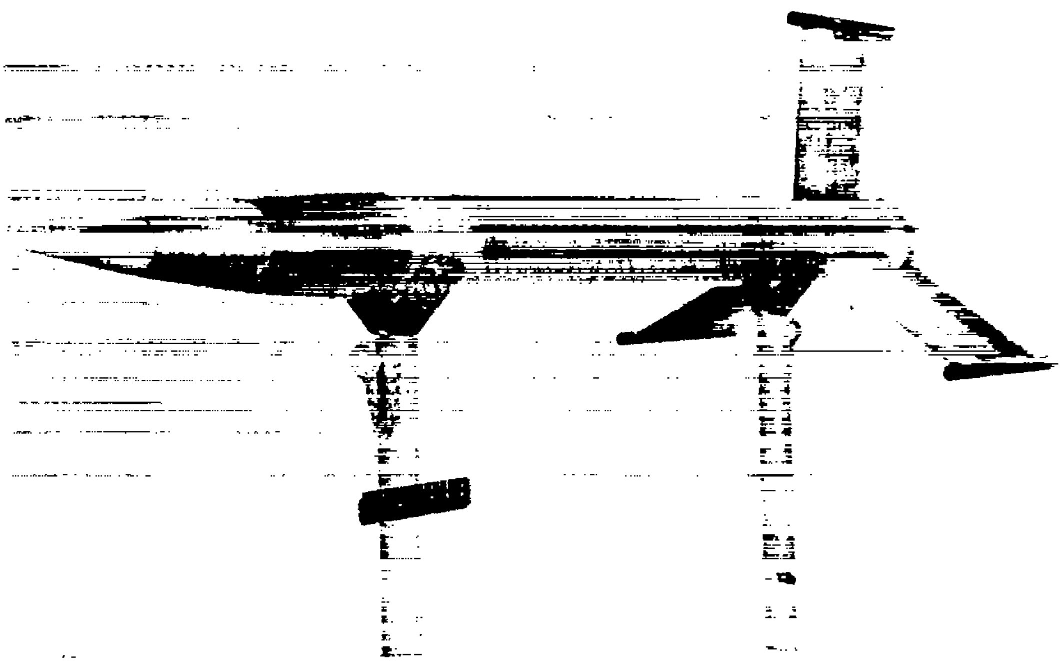
(d) Trailing-edge jet-spoiler details.

Figure 1.- General arrangement and details of leading-edge and trailing-edge jet-spoiler models. All linear dimensions in inches.

[redacted]

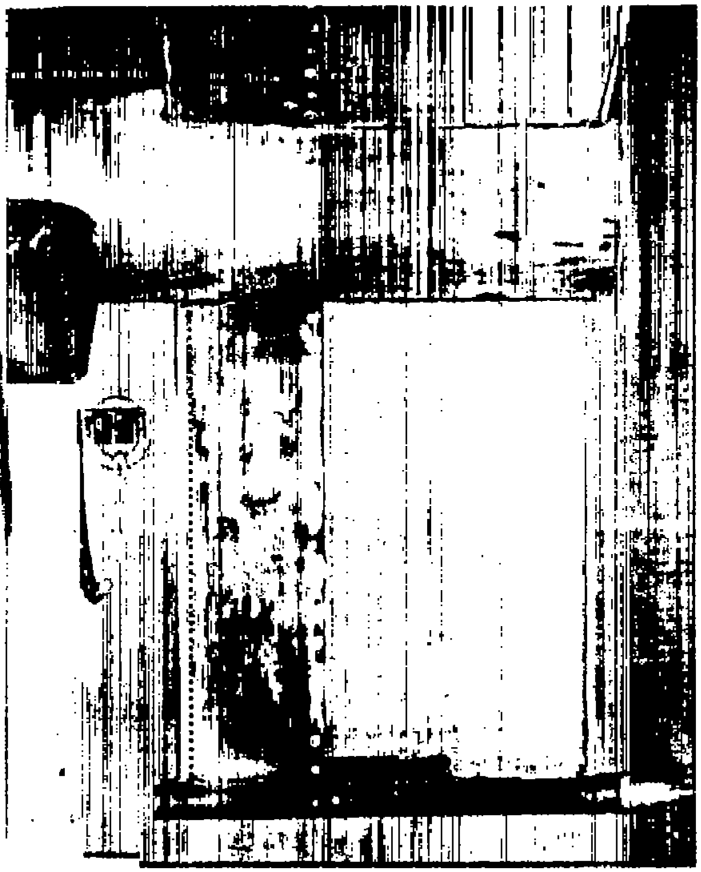


(a) Three-quarter front view of leading-edge-spoiler model.

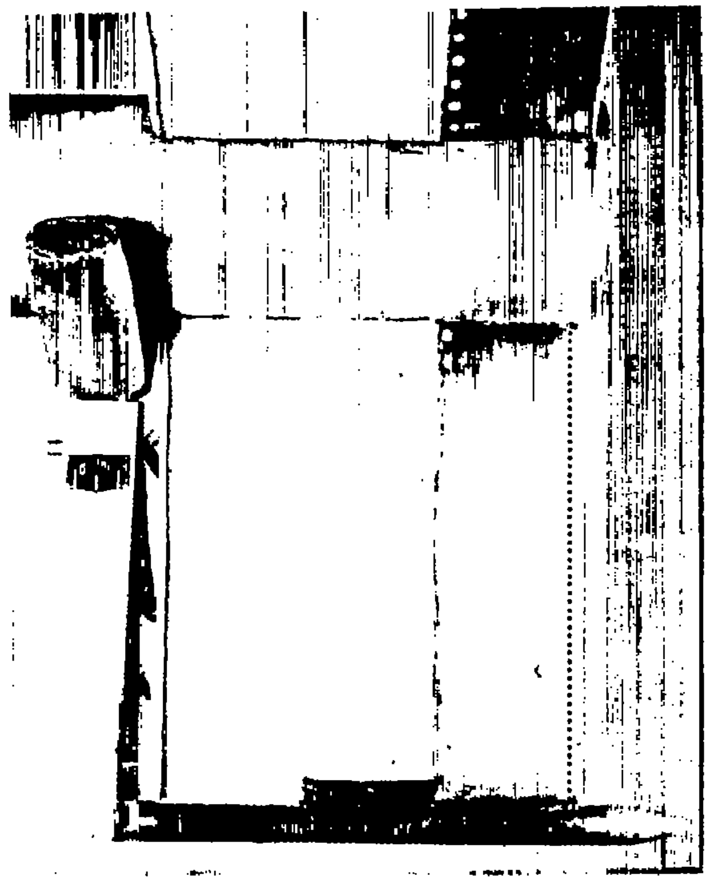


(b) Three-quarter front view of trailing-edge-spoiler model. L-57-1596

Figure 2.- Photographs of models.

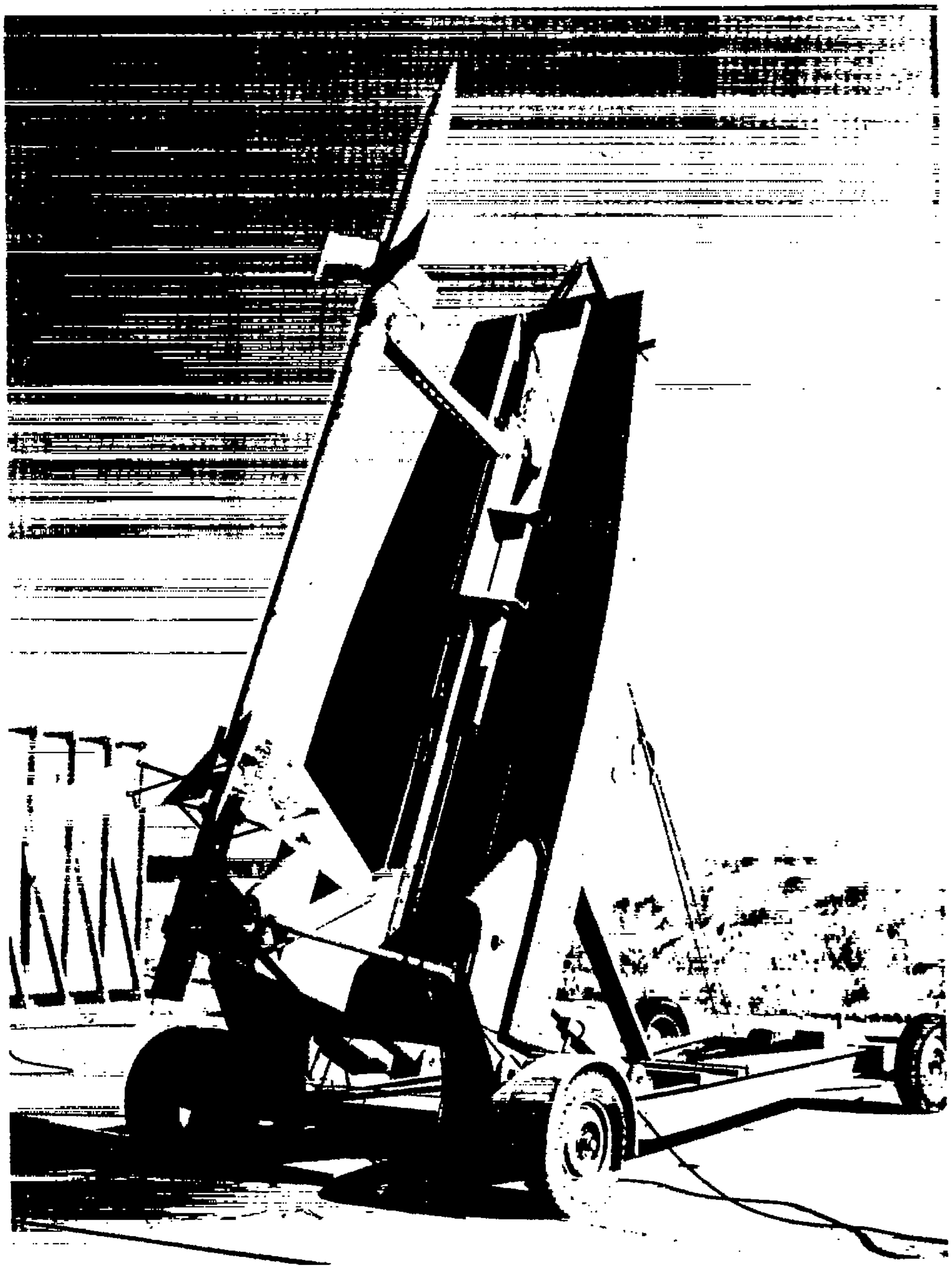


(c) Leading-edge-spoiler panel.



(d) Trailing-edge-spoiler panel. L-57-1597

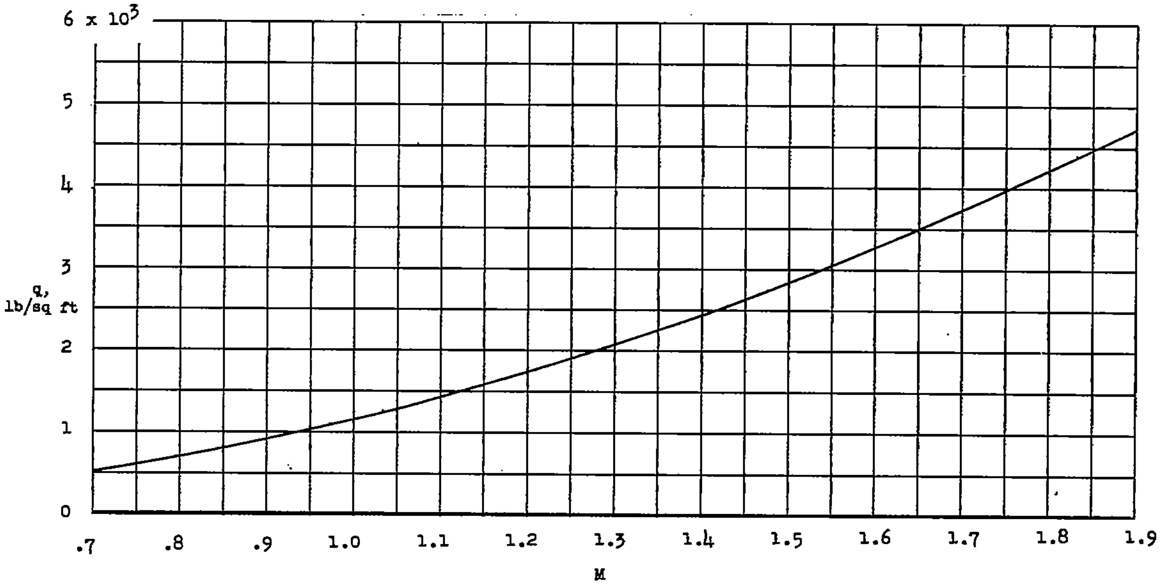
Figure 2.- Continued.



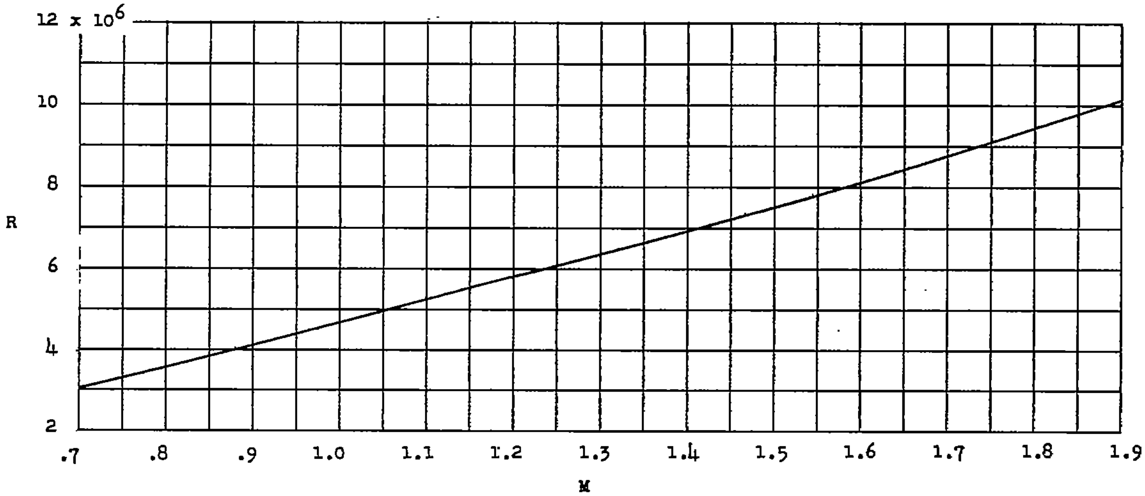
L-96114

(e) Trailing-edge-spoiler model on launcher.

Figure 2.- Concluded.



(a) Dynamic pressure.



(b) Reynolds number.

Figure 3.- Variation of dynamic pressure and Reynolds number with Mach number.

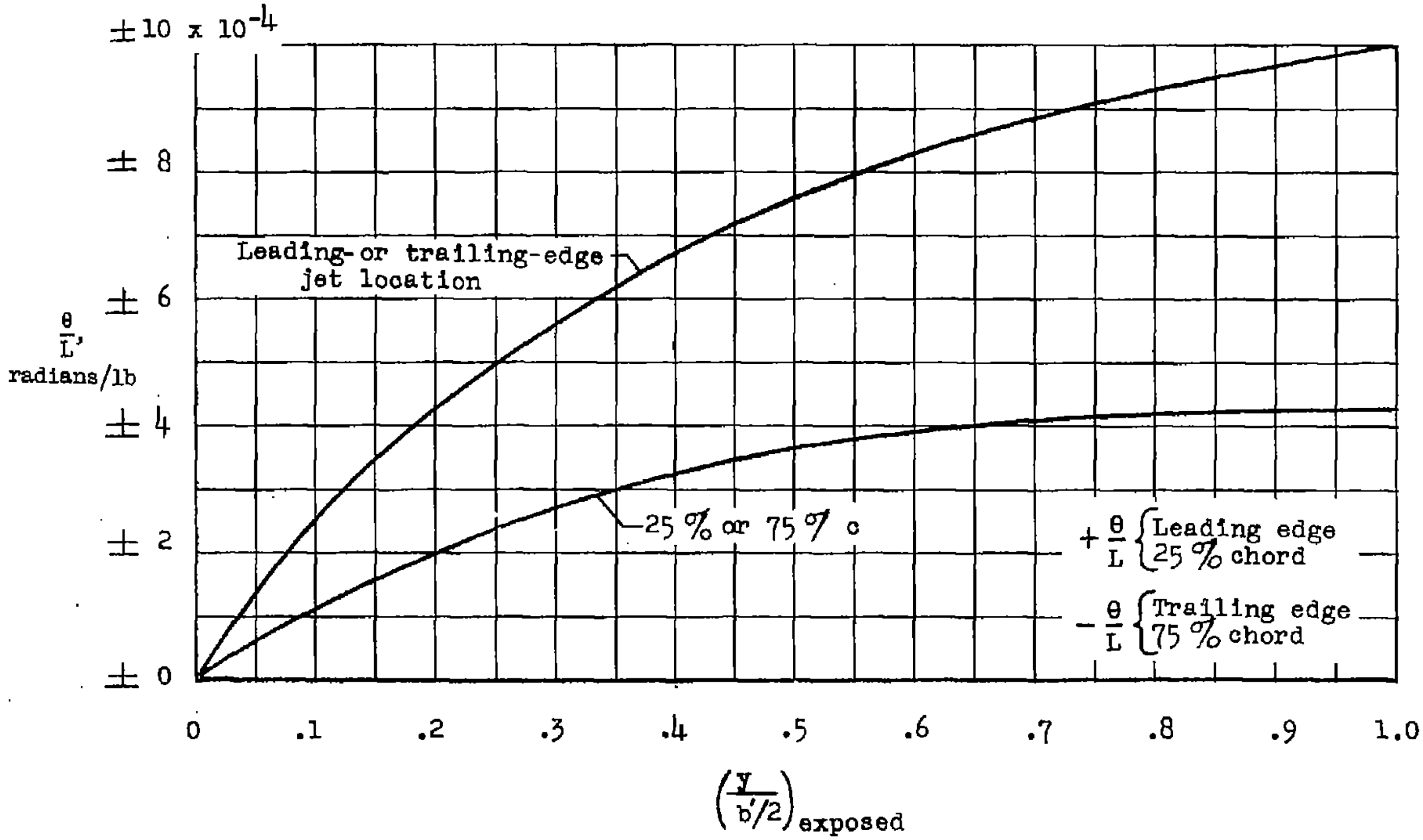


Figure 4.- Variation of wing twist with spanwise location for a uniform load distributed along the leading-edge and trailing-edge jet positions and the 25 percent and 75 percent chord lines.

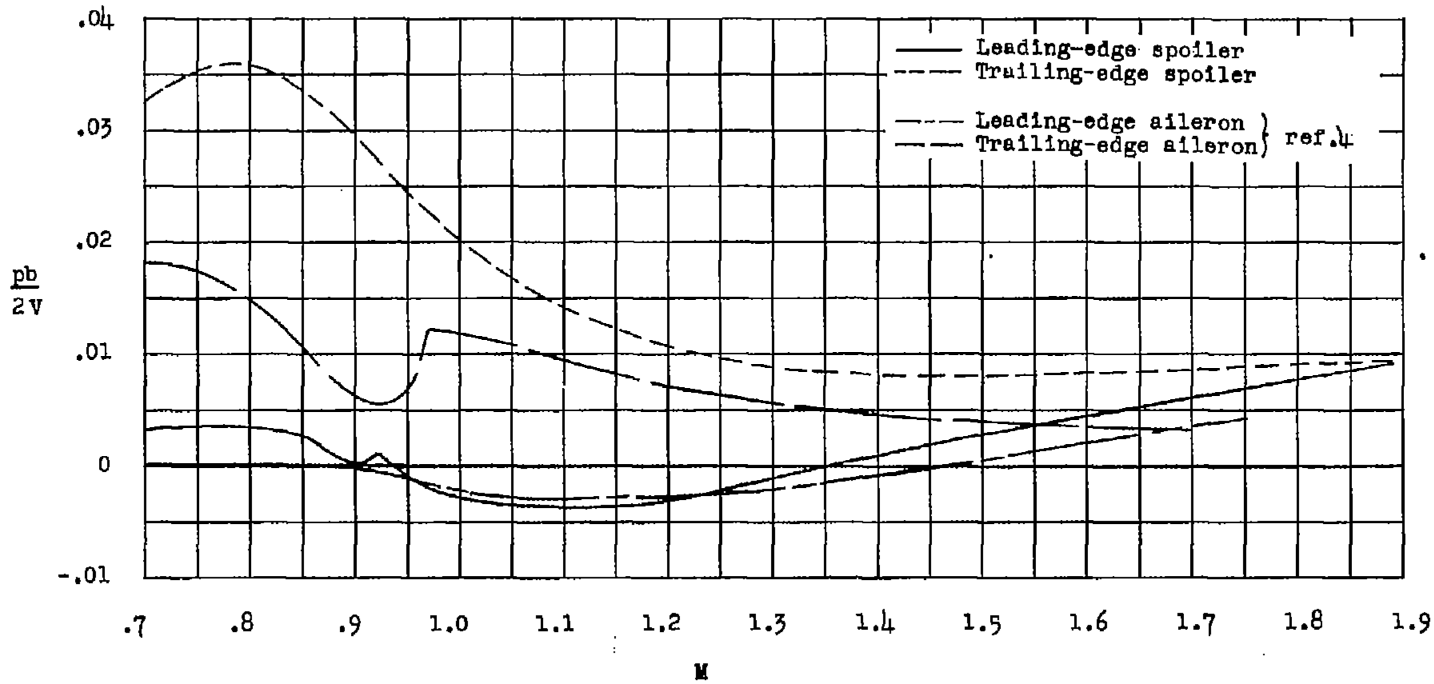


Figure 5.- Variation of rolling effectiveness of leading-edge and trailing-edge air-jet spoilers and ailerons (deflected 1°).

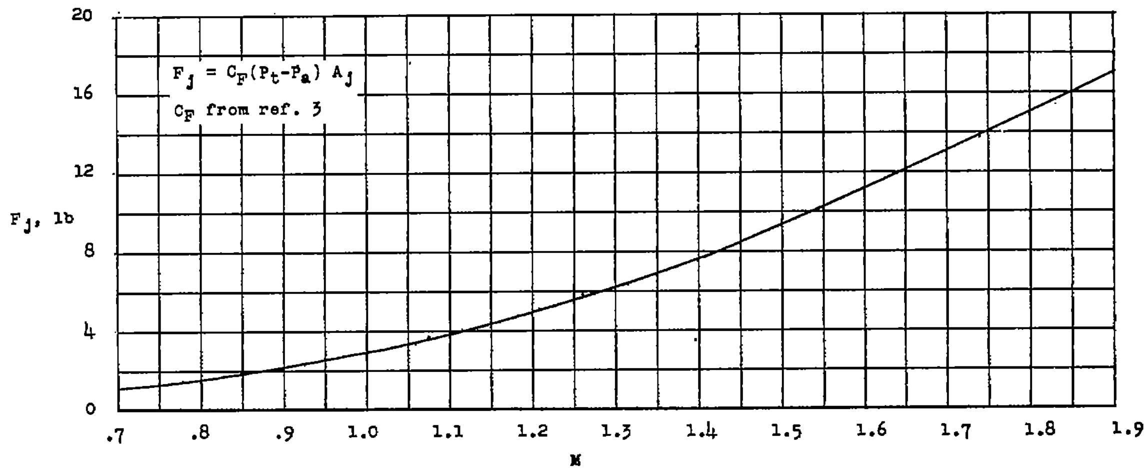


Figure 6.- Variation with Mach number of leading-edge and trailing-edge jet force per wing panel.

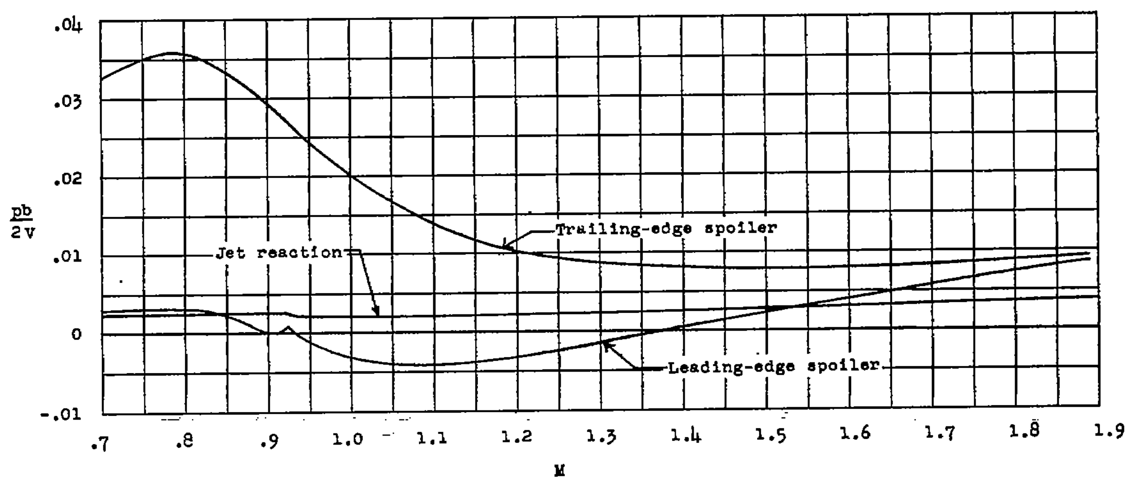


Figure 7.- Variation with Mach number of pb/2V of each model and pb/2V caused by jet reaction.

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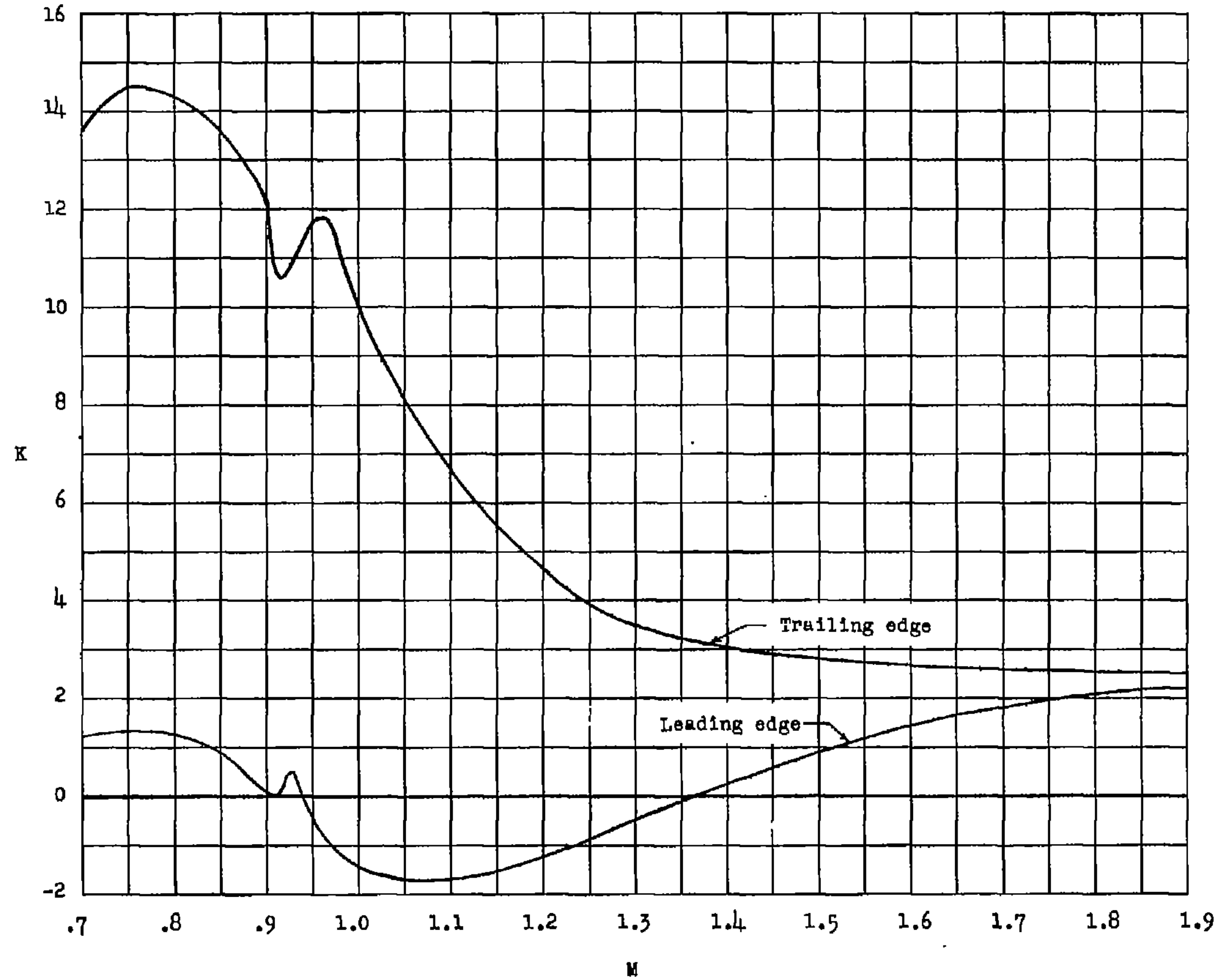

Figure 8.- Variation with Mach number of the magnification factor K for each model.

[redacted]