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(NASA-TM-X-3166) LOW-SPEED WIND-TUNNEL INVESTIGATION OF FORWARD-LOCATED SPOILERS AND TRAILING SPLINES AS TRAILING-VORTEX HAZARD-ALLEVIATION DEVICES ON AN ASPECT-RATIO-8 WING MODEL (NASA) 26 p HC H1/01

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LOW-SPEED WIND-TUNNEL INVESTIGATION OF FORWARD-LOCATED SPOILERS AND TRAILING SPLINES AS TRAILING-VORTEX HAZARD-ALLEVIATION DEVICES ON AN ASPECT-RATIO-8 WING MODEL

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16. Abstract

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The trailing-wing rolling-moment data taken in the tunnel diffuser section show good agreement with the data taken in the tunnel test section. This agreement indicates that reasonable results may be obtained in the Langley V/STOL tunnel in experimental investigations of the trailing-vortex hazard at relatively great distances behind aircraft models.

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SUMMARY

An investigation was made in the Langley V/STOL tunnel in order to determine, by the trailing-wing sensor technique, the effectiveness of either a forward-mounted spoiler or a tip-mounted spline as trailing-vortex attenuation devices on an unswept aspect-ratio-8 wing model.

The trailing-wing rolling-moment data taken in the tunnel diffuser section show good agreement with the data taken in the tunnel test section. This agreement indicates that reasonable results may be obtained in the Langley V/STOL tunnel in experimental investigations of the trailing-vortex hazard at relatively great distances behind aircraft models.

At distances up to 100 wing-chord lengths downstream of the model without flaps (at a lift coefficient of 0.5), the trailing-wing rolling-moment coefficients were reduced by about 25 percent when either the forward-located outboard spoiler or the trailing spline was used as a vortex-alleviation device. Beyond 100 chords downstream the effectiveness decreased and at about 160 chords downstream there was no effect of either device.

For the model with a single-slotted flap (at a lift coefficient of 1.25), the forward-located midspan spoiler produced about a constant 25-percent reduction of the trailing-wing rolling-moment coefficient at downstream distances up to 180 chords, which was the limit of the investigation. In contrast, the spline reduced the trailing-wing rolling moment very little in the near field, but it did become more effective with increasing downstream distances. At 180 chords downstream, about a 20-percent reduction in the trailing-wing rolling-moment coefficient was obtained.

INTRODUCTION

The strong vortex wakes generated by large transport aircraft are a potential hazard to smaller aircraft. The National Aeronautics and Space Administration has been requested by the Federal Aviation Administration to determine the feasibility of reducing this hazard by aerodynamic means.

Previous work (ref. 1) has shown that the magnitude of the vortex-wake hazard is greatly influenced by the direction of the flight of the aircraft which is penetrating the trailed vortices. As discussed in reference 1, a cross-track penetration at right angles to the trailing vortices tends to cause pitching and vertical motion and to produce vertical loads on the penetrating airplane in a manner similar to that of a gust encounter. Also, an along-track penetration, parallel to and between the wing-tip vortices, can occur in both the take-off climbout and the landing approach and may cause settling or, at least, may reduce the rate of climb of the penetrating aircraft. However, an along-track penetration through the vortex center is considered to be the most hazardous encounter since such penetration would induce a rolling motion to the penetrating aircraft that could result in an upset.

One approach in assessing the trailing-vortex hazard is to determine the velocity profile of the vortex and, by integrating the velocity profile over the span of the penetrating aircraft, the induced rolling moment can be inferred. Detailed measurements of the velocity profile through the trailing vortex have been obtained by the use of attitude sensor vanes and total-pressure probes (ref. 2), yawheads (ref. 3), tuft grids (ref. 4), vortex meters (ref. 5), and hot-wire anemometers (ref. 6).

Another approach in assessing the trailing-vortex hazard is to simulate an airplane flying in the trailing vortex and to make direct measurements of the individual rolling moments. Therefore, a sensor technique which allows direct measurements of the rolling moment induced by the trailing vortices from a lifting airplane model on a model mounted downstream at various distances was developed in the Langley V/STOL tunnel.

The purpose of this investigation was to use the direct measurement technique in the Langley V/STOL tunnel in order to determine the induced rolling moment on a trailing model in the near and far field caused by the trailing vortex generated by an aspect-ratio-8 wing model, and also to determine the effectiveness of either a forward-located spoiler or a trailing drag device (hereafter referred to as a spline) as a vortex hazard-alleviation device.

SYMBOLS

All data are presented with respect to the wind axes. The pitching-moment coefficients are referred to the quarter chord of the wing mean aerodynamic chord.

b wing span, m

C_D drag coefficient, $\frac{\text{Drag}}{qS_M}$

C_L lift coefficient, $\frac{\text{Lift}}{qS_M}$

$C_{l_{TW}}$ trailing-wing rolling-moment coefficient, $\frac{\text{Trailing-wing rolling moment}}{qS_{TW}b_{TW}}$

C_m pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS_M\bar{c}_M}$

c wing chord, m

$\bar{c}$ wing mean aerodynamic chord, m

q dynamic pressure, N/m^2

S wing area, m^2

Y,Z lateral and vertical dimensions

α angle of attack, deg

Subscripts:

M aspect-ratio-8 model

TW trailing wing

MODEL AND APPARATUS

Sketches of the aspect-ratio-8 vortex-generating models are shown in figure 1. Two sizes of vortex-generating models were used during this investigation. One had a span of 2.438 m and was tested in the rear and forward bays of the V/STOL tunnel. (See figs. 2 to 4.) The other had a span of 1.219 m and was tested in the forward bay of the V/STOL tunnel. (See figs. 4 and 5.) Each of the vortex-generating model wings was unswept and had an aspect ratio of 8, a taper ratio of 1, and an NACA 0012 airfoil section. For some of the tests, a 30-percent-chord, three-quarter-span, single-slotted flap, which had an NACA 0012 airfoil section, was installed as shown in figures 1 and 5. Details of the spoilers and the trailing drag device (spline) are given in figure 1.

The trailing-wing models had a span equal to one-quarter of the span of the generating-model wings, a chord equal to 30 percent of the chord of the generating-model wing, and an NACA 0012 airfoil section.

The Langley V/STOL tunnel has a test-section height of 4.42 m, a width of 6.63 m, and a length of 15.24 m. The vortex-generating models were sting supported on a six-component, strain-gage balance system which measured their forces and moments. The angle of attack was determined from an electrical inclinometer mounted in the fuselage. The trailing models were mounted on a single-component, strain-gage roll balance, which was attached to a traverse mechanism capable of moving the model both laterally and vertically. (See fig. 6.) The lateral and vertical positions of the trailing model were measured by electrical potentiometers. This entire traverse mechanism could be mounted to the tunnel floor at various tunnel longitudinal positions downstream of the vortex-generating model, as shown in figure 4.

TESTS AND CORRECTIONS

Vortex-Generating Models

All tests were run at a free-stream dynamic pressure in the tunnel test section of 430.90 N/m^2 which corresponds to a velocity of 27.4 m/sec. The Reynolds numbers for these tests were approximately 5.74×10^5 and 2.87×10^5, based on the chord of the larger wing and the smaller wing, respectively. The basic longitudinal aerodynamic characteristics were obtained through an angle-of-attack range of approximately -4° to 13°.

Blockage corrections were applied to the data by the method of reference 7. Jet-boundary corrections to the angle of attack and to the drag were applied in accordance with reference 8.

Trailing-Wing Model

The trailing-wing model and its associated roll-balance system were used as a sensor to measure the induced rolling moment caused by the vortex flow downstream of the generating model. The trailing model was positioned at a given distance downstream of the generating model and the vortex-generating model was set at an angle of attack necessary to provide the desired lift coefficient. With the tunnel operating at a low speed ($q \leqq 200$ N/m^2), the trailing vortex was made visible by smoke which was ejected near the wing tip. (See fig. 2.) The traverse mechanism was positioned laterally and vertically so that the trailing vortex was near the center of the mechanism. The tunnel was then brought up to the test dynamic pressure and the trailing vortex was probed with the trailing model. A large number of trailing-wing rolling-moment data points (usually from 50 to 100) was obtained from the lateral traverses at several vertical locations. From these data, contour plots of constant rolling-moment coefficients were constructed as shown in figure 7. From contour plots such as these, the maximum rolling-moment coefficient and the location of the vortex core relative to the generating wing were determined.

Trailing-wing rolling-moment measurements were made at downstream distances from 5 to 180 chord lengths behind the generating models. (See fig. 4.) A large portion of the trailing-wing rolling-moment data was obtained with the trailing model positioned in the diffuser section of the V/STOL tunnel. These data were reduced to coefficient form based on the local dynamic pressure at the trailing-model location. The vortex-core location relative to the wing tip of the generating model has been corrected in order to account for the progressively larger tunnel cross-sectional area in the diffuser section.

RESULTS AND DISCUSSION

Vortex-Generating Model

The longitudinal aerodynamic characteristics of the 2.438-m span model without flaps and with the three-quarter-span, single-slotted flaps installed are presented in figures 8 and 9, respectively. These results indicate that the splines did not appreciably alter the lift characteristics of the model. They act essentially as a pure drag device adding a constant increment of drag throughout the angle-of-attack range.

These results also indicate that the forward-located spoilers act not only to produce drag, but also to modify the lift characteristics of the model. The lift-curve slope was reduced and the span-load distribution apparently was altered because of the forward-located spoiler.

Trailing-Wing Model

The position of the trailing vortex and the induced rolling-moment coefficient on the trailing-wing model at various downstream distances behind the vortex-generating wing are presented in figures 10 and 11 for the wing without flaps and the wing with flaps, respectively. Each data point in figures 10 and 11 was obtained from contour plots such as figure 7. These data were obtained from four different tests in the V/STOL tunnel. Two of the tests were for the 2.438-m-span vortex-generating model mounted in the rear bay. (See figs. 2 and 4.) The other two tests were for the 2.438-m-span and the 1.219-m-span vortex-generating models mounted in the forward bay. (See figs. 3 and 4.) The symbols at the bottom of these data figures (figs. 10 and 11) indicate the location of the aft end of the tunnel test section for each of these sets of data. The data at downstream distances greater than indicated by the bottom symbols are data obtained with the trailing model in the diffuser section of the tunnel.

By using the two sizes of models and testing them at the various tunnel locations indicated in figure 4, a direct comparison of trailing-wing rolling-moment data obtained in the tunnel test section can be made with trailing-wing rolling-moment data obtained in the tunnel diffuser section.

It can be seen in figures 10 and 11 that the values of the trailing-wing rolling-moment coefficients measured downstream of the vortex-generating model are generally lower when the large vortex-generating model was mounted in the rear bay of the tunnel as compared with when the large vortex-generating model was mounted in the forward bay of the tunnel. These differences may be due to the two different model support systems used during these investigations. (See figs. 2, 3, and 4.) The relatively small differences noted in the values of the trailing-wing rolling-moment coefficients measured downstream of the two sizes of the vortex-generating models when mounted in the forward bay of the tunnel, when both models were tested on the same model support system, may be attributed to the random nature of a trailed vortex. However, it can be seen from figures 10 and 11 that the measured trailing-wing rolling-moment data and the vortex-core locations obtained in the tunnel test section agree reasonably well with the data obtained in the tunnel diffuser section. Based on this agreement, reasonable results may be obtained in the Langley V/STOL tunnel in experimental studies of the vortex hazard at relatively great distances behind aircraft models (in this case, distances up to about 200 chords).

The effectiveness of the forward-located spoilers and the effectiveness of the trailing splines in reducing the trailing-wing rolling-moment coefficients are compared in figure 12 for the generating model without flaps at $C_L = 0.5$ and in figure 13 for the generating model at $C_L = 1.25$ with a single-slotted flap installed. The data in figure 12 indicate that, for the generating model without flaps, the trailing-wing rolling moment obtained at downstream distances up to 100 chord lengths was reduced by about 25 percent when either the outboard spoilers or the trailing spline was used as a vortex-attenuation device. However, beyond 100 chords downstream, these data indicate that the effectiveness of the devices decreased and, at about 160 chords downstream, both devices become ineffective in reducing the rolling moment experienced by the trailing model.

The data for the generating model with a single-slotted flap installed (fig. 13) show that the midspan spoiler was more effective than the trailing spline in reducing the trailing-wing rolling moment throughout the downstream distances of the investigation (up to 180 chord lengths). It is of interest to note that the 25-percent rolling-moment coefficient reduction caused by the midspan spoiler was essentially constant over this distance. Although the trailing spline had almost no effect near the generating wing, it did develop some effectiveness with increasing downstream distance and approached the effectiveness of the midspan spoiler at the largest downstream distance with about a 20-percent reduction in the rolling-moment coefficient. It should be recognized that these data are no indication of the effectiveness of either device at a greater downstream distance.

CONCLUDING REMARKS

Results have been presented of an investigation in the Langley V/STOL tunnel to determine, by the trailing-wing sensor technique, the effectiveness of either a forward-mounted spoiler or a tip-mounted drag device (spline) as trailing-vortex attenuation devices on an unswept aspect-ratio-8 wing model.

Based on the agreement between the overlap data of the trailing-wing rolling moments taken in the tunnel test section and in the tunnel diffuser section, reasonable results may be obtained in the Langley V/STOL tunnel in experimental investigations of the trailing-vortex hazard at relatively great distances behind aircraft models.

The trailing-wing rolling-moment coefficients obtained at distances up to 100 chords downstream of the model without flaps at a lift coefficient of 0.5 were reduced by about 25 percent when either the outboard spoiler or the trailing spline was used as a vortex-attenuation device. However, beyond 100 chords downstream the effectiveness decreased, and at about 160 chords downstream both devices become ineffective.

For the model with a single-slotted flap at a lift coefficient of 1.25, the midspan spoiler produced about a constant 25-percent reduction of the trailing-wing rolling-moment coefficient at a downstream distance up to 180 chords, which was the limit of this investigation. In contrast, the trailing spline reduced the trailing-wing rolling moment very little near the generating wing. However, the trailing spline did become more effective with increasing downstream distances and at 180 chords downstream about a 20-percent reduction in trailing-wing rolling-moment coefficient was obtained.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., December 18, 1974.

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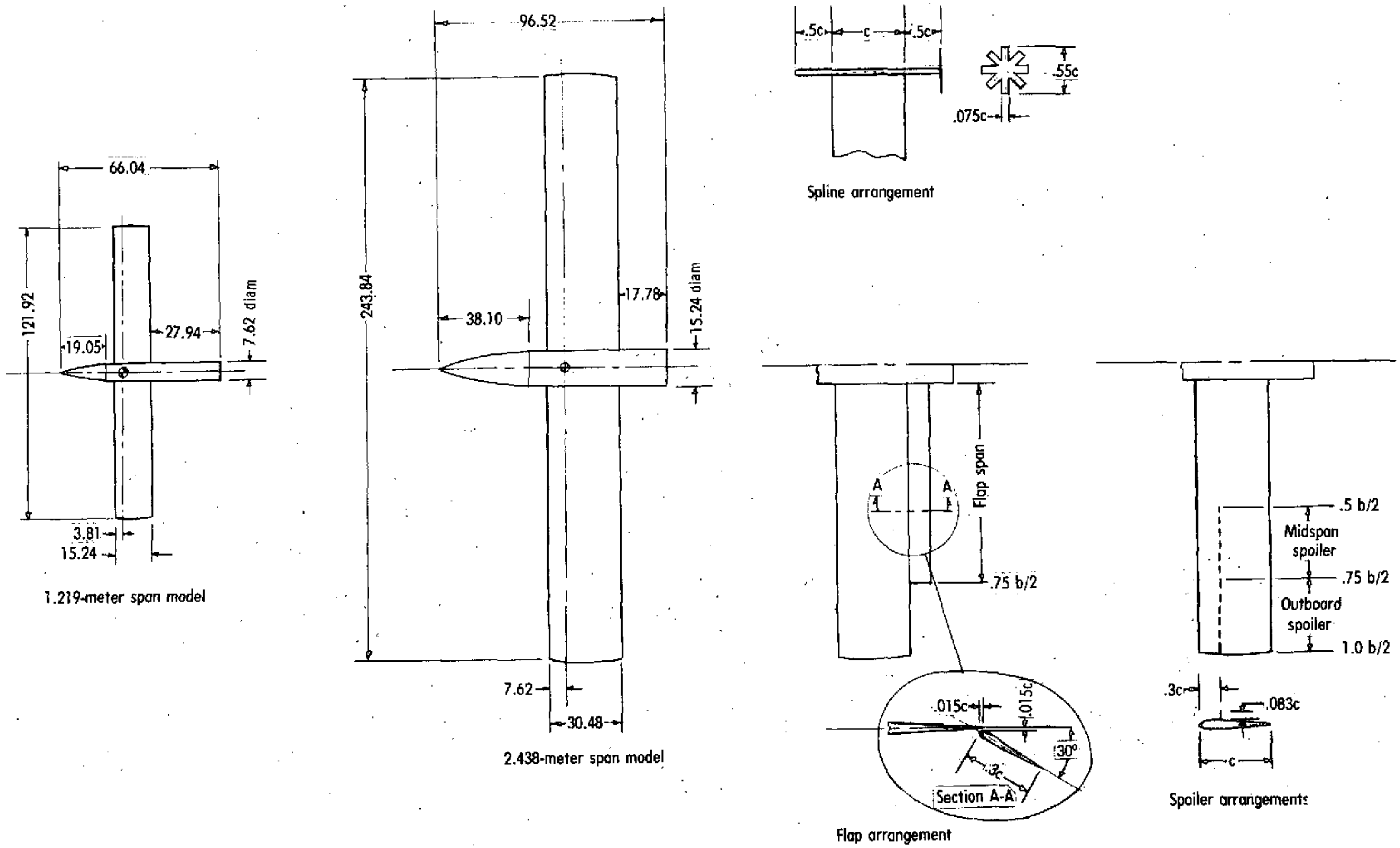

Figure 1.- Sketch of aspect-ratio-8 models. Wing and flap both have NACA 0012 airfoil sections. Linear dimensions are in cm.

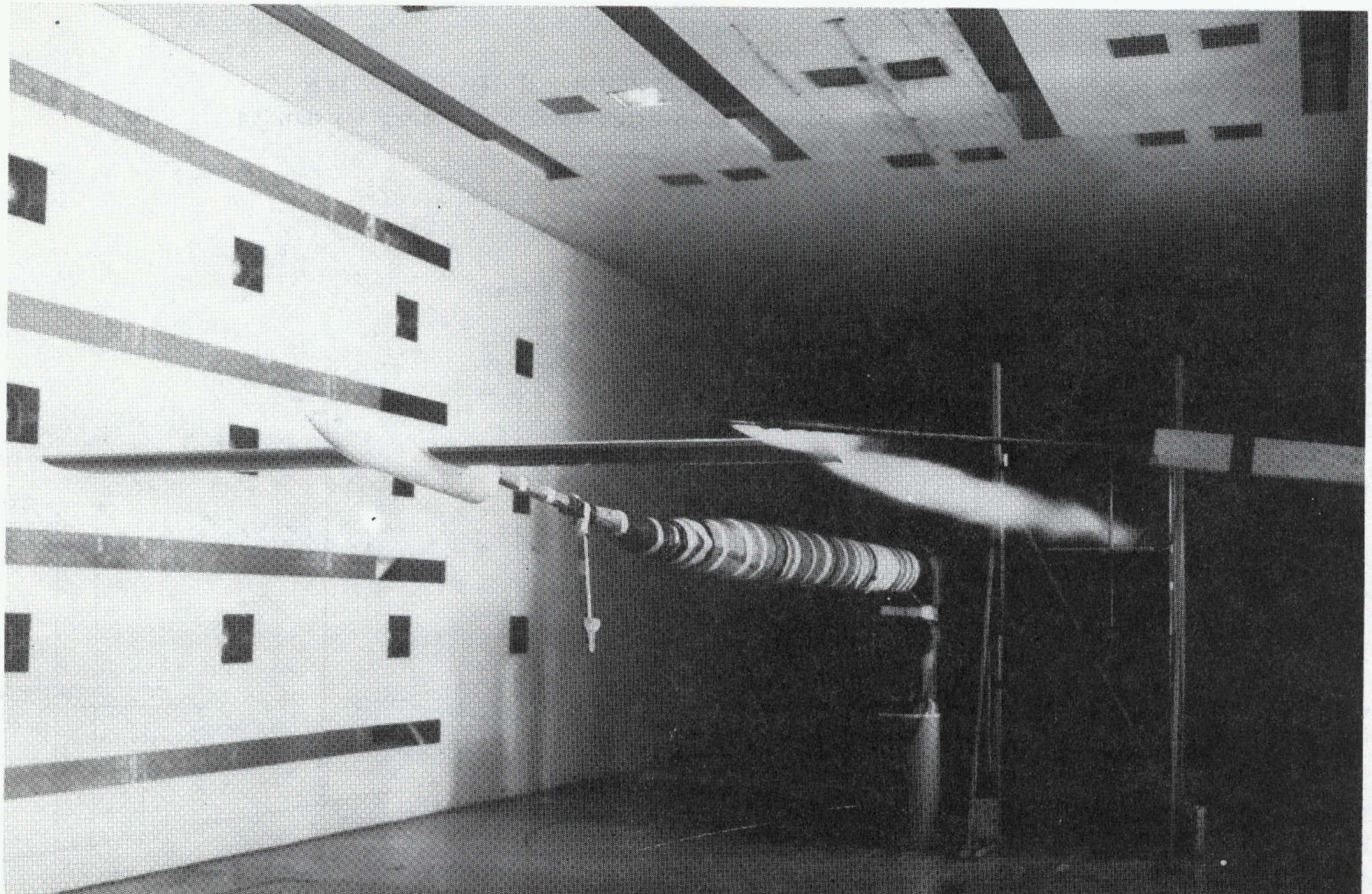

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Figure 2.- Photograph of the 2.438-meter-span aspect-ratio-8 model mounted at rear position in Langley V/STOL tunnel. The 0.610-meter-span trailing wing is located at the 20-chord downstream position. Smoke shows trailing-vortex location.

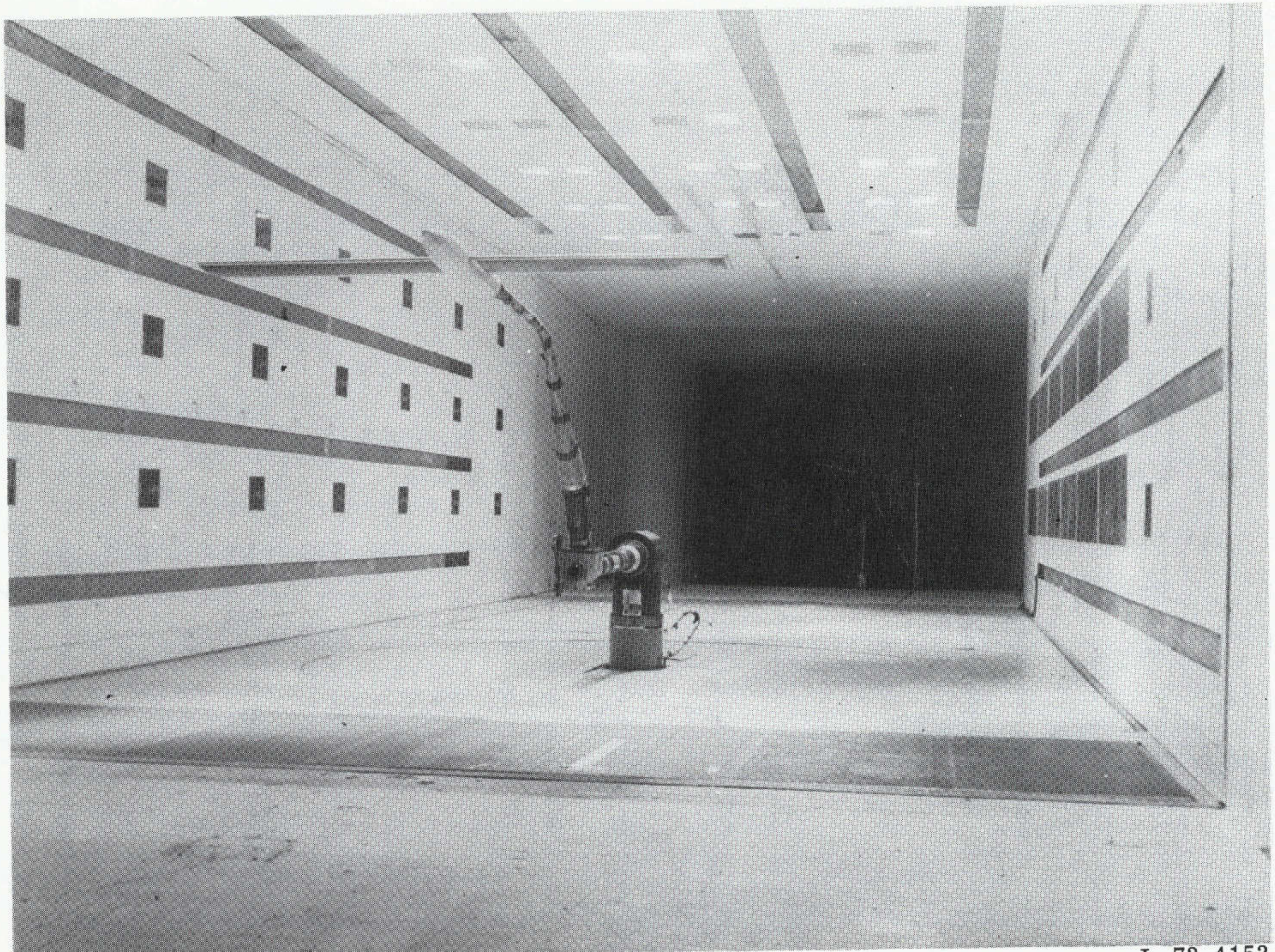

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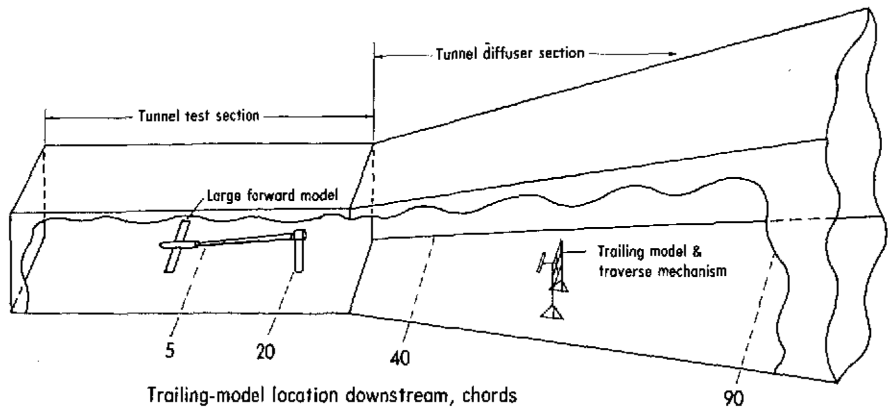
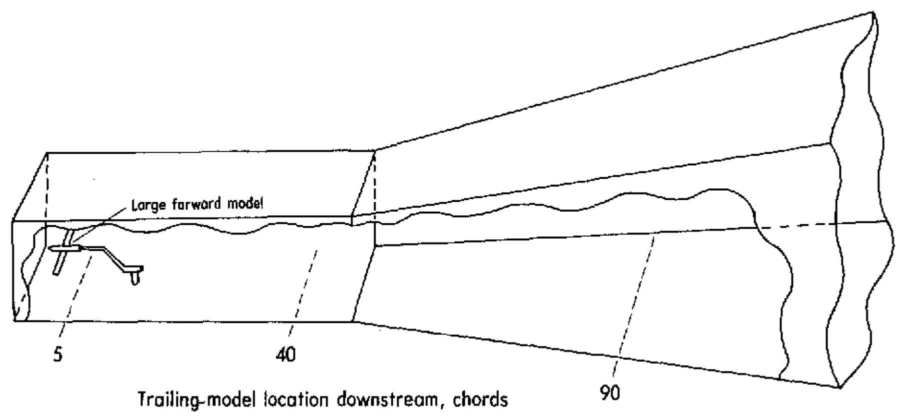
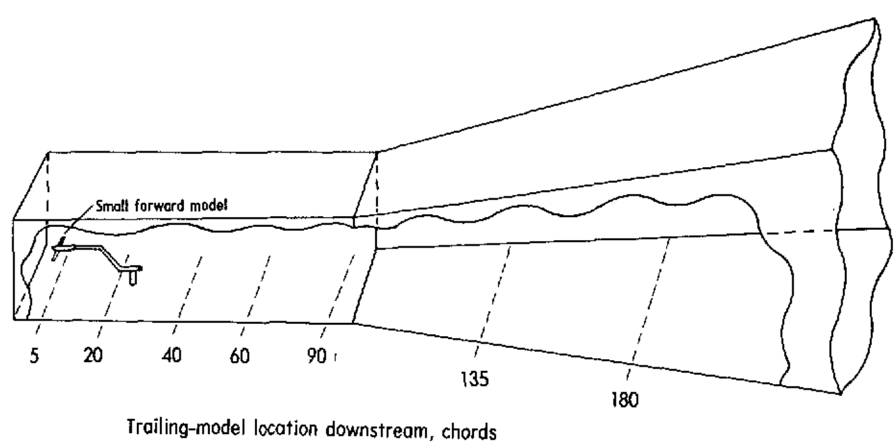
Figure 3.- Photograph of the 2.438-meter-span aspect-ratio-8 model mounted at the forward position in Langley V/STOL tunnel. The 0.610-meter-span trailing wing is located at the 90-chord downstream position.



(a) Large model mounted in rear bay.



(b) Large model mounted in forward bay.



(c) Small model mounted in forward bay.

Figure 4.- Schematics showing relative position in V/STOL tunnel of forward and trailing models.

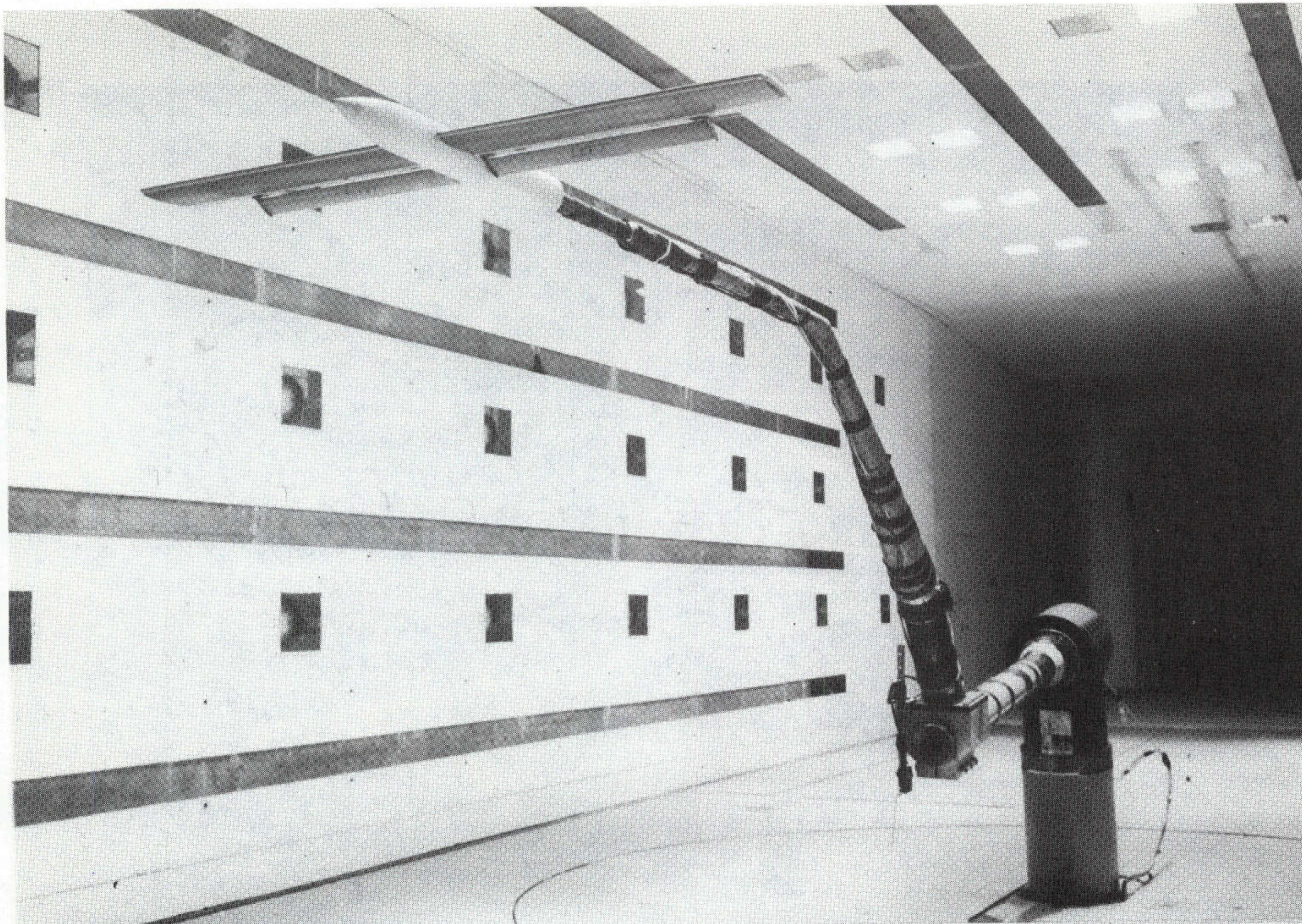


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Figure 5.- Photograph of the 1.219-meter-span aspect-ratio-8 model mounted at forward position in Langley V/STOL tunnel.

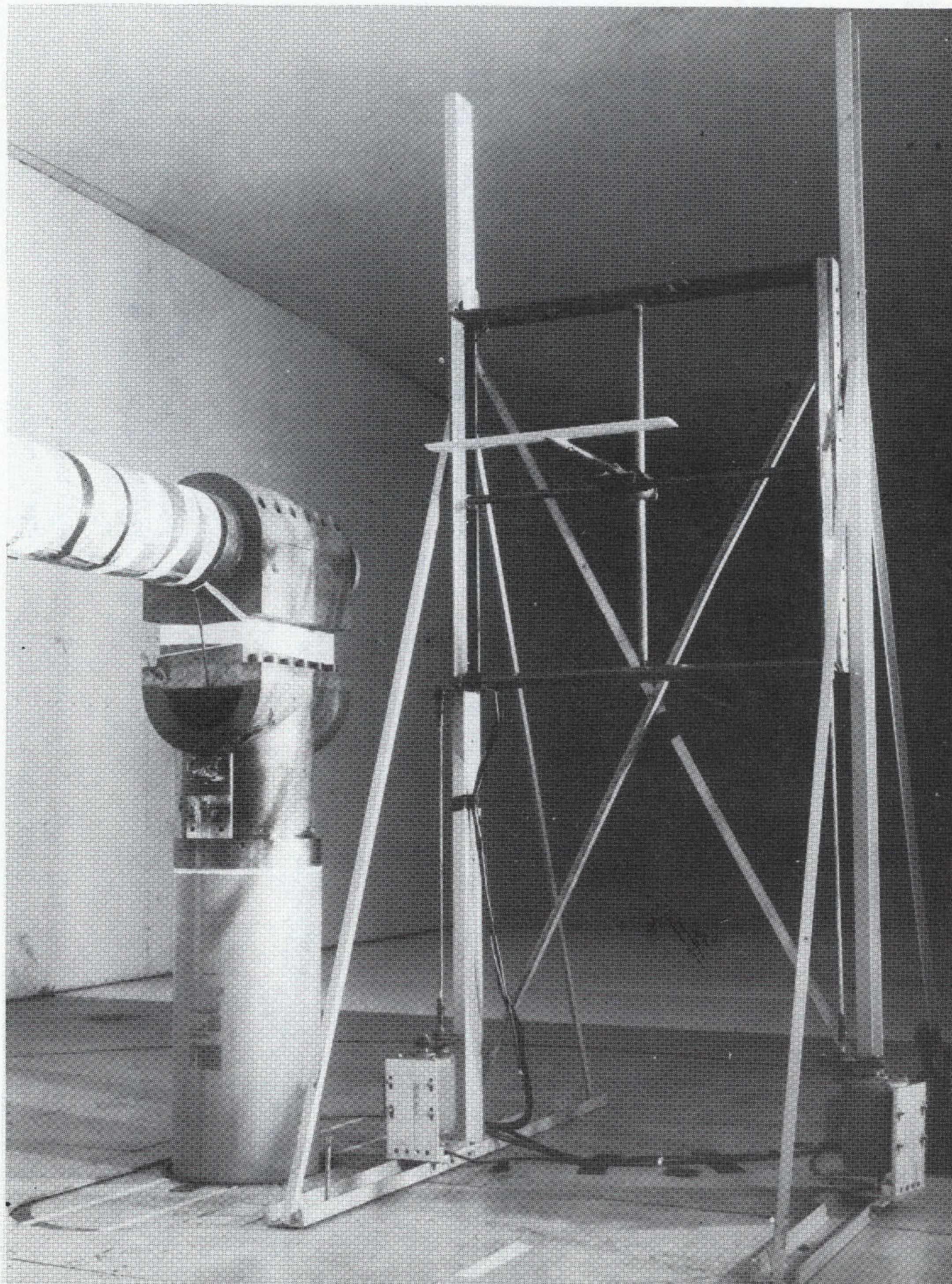

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Figure 6.- Photograph of trailing-wing traverse mechanism in the Langley V/STOL tunnel.

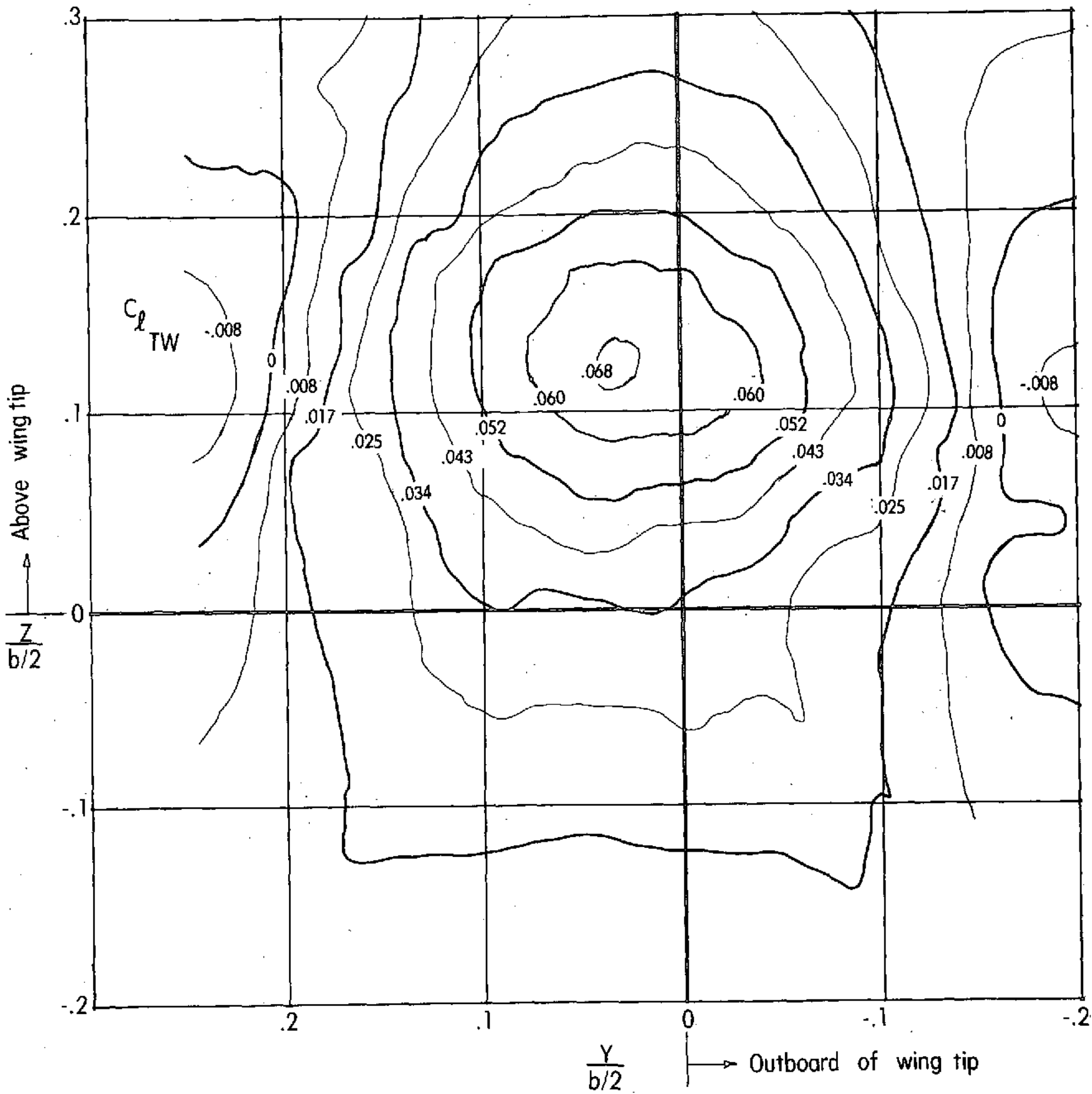


Figure 7.- Contour plot of trailing-wing rolling-moment coefficients measured 5 chords downstream of the 1.219-meter-span model equipped with mid-span spoilers ($C_L = 0.5$).

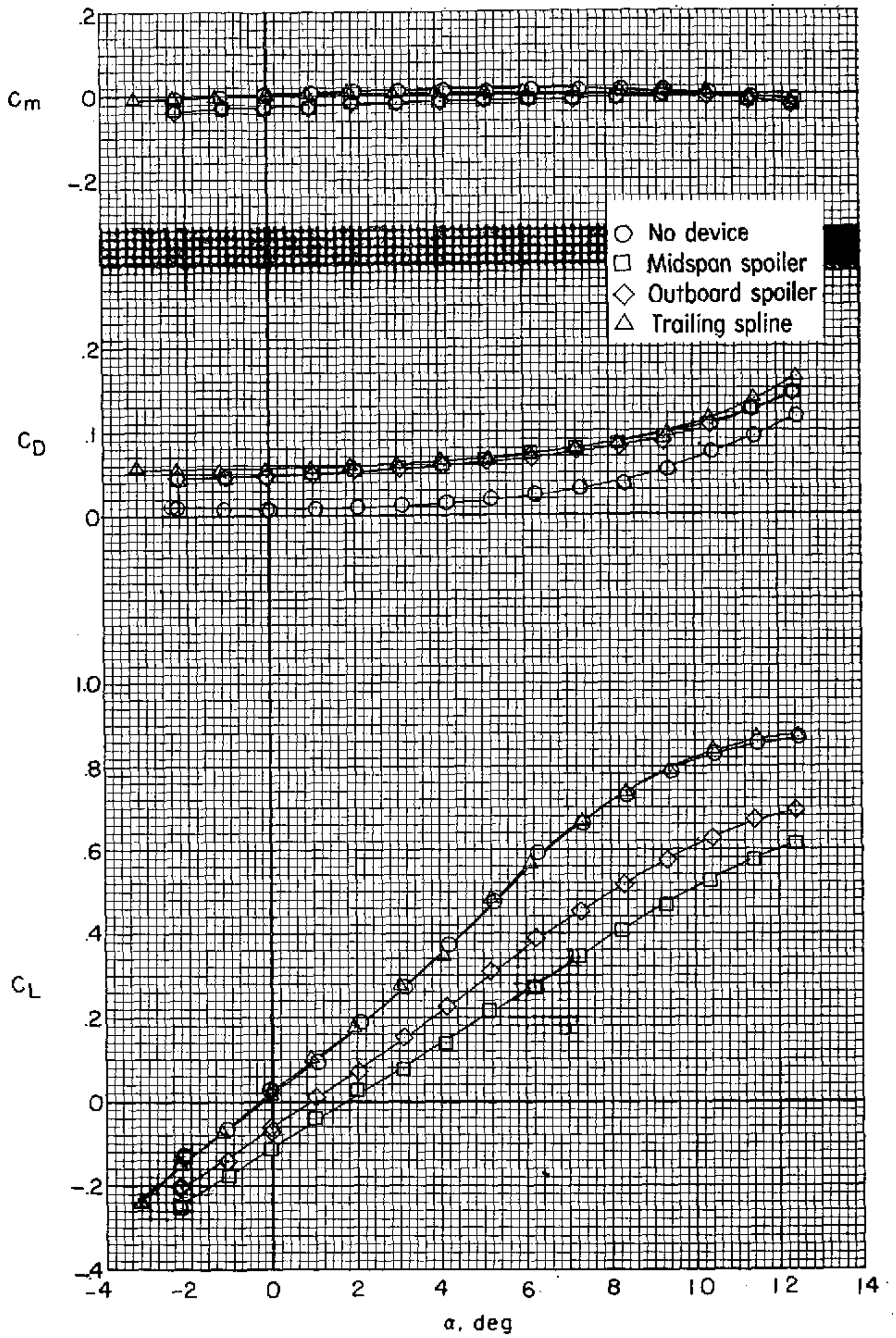


Figure 8.- Effect of midspan spoiler, outboard spoiler, and trailing spline on the longitudinal aerodynamic characteristics of the 2.438-meter-span aspect-ratio-8 model.

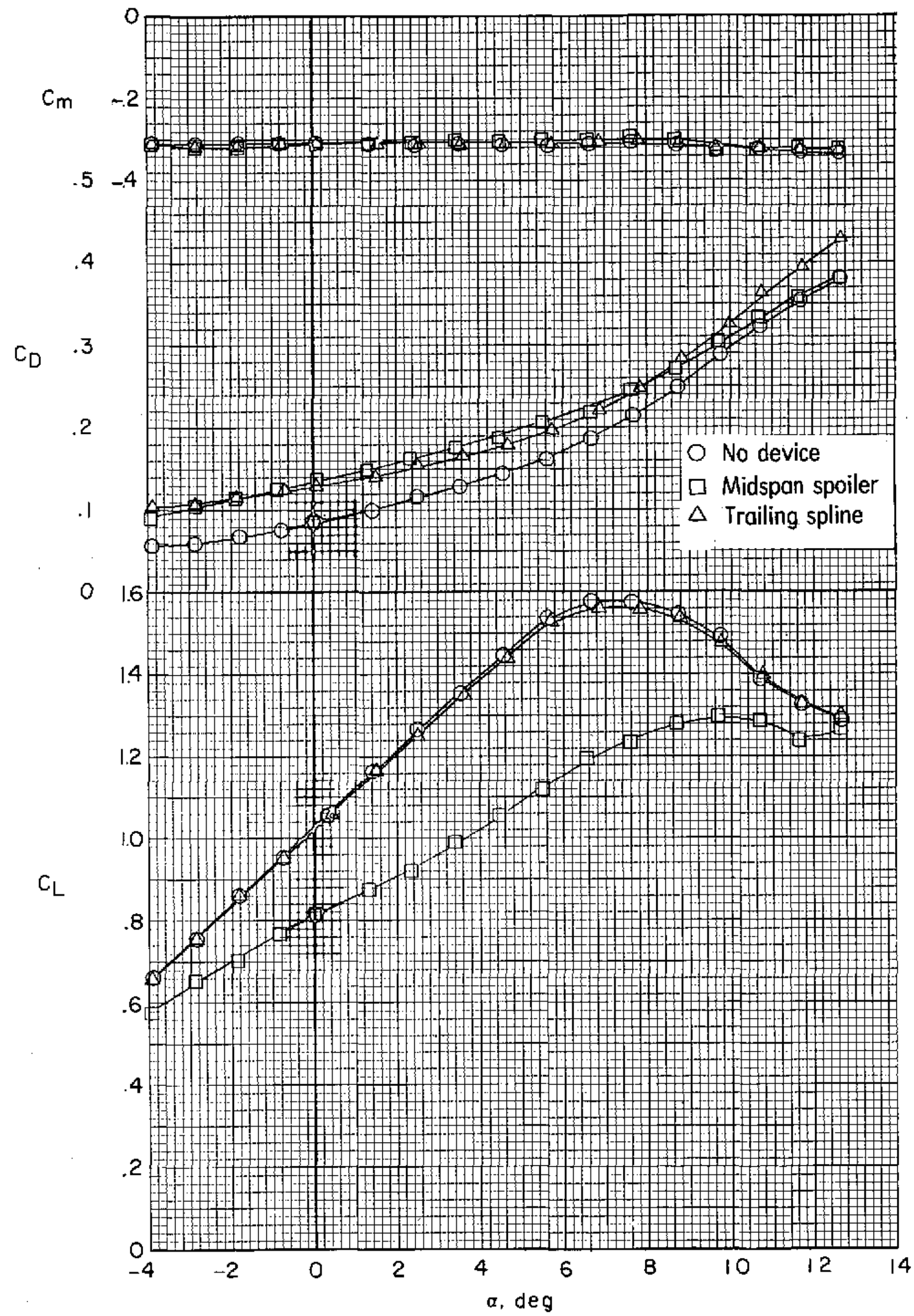
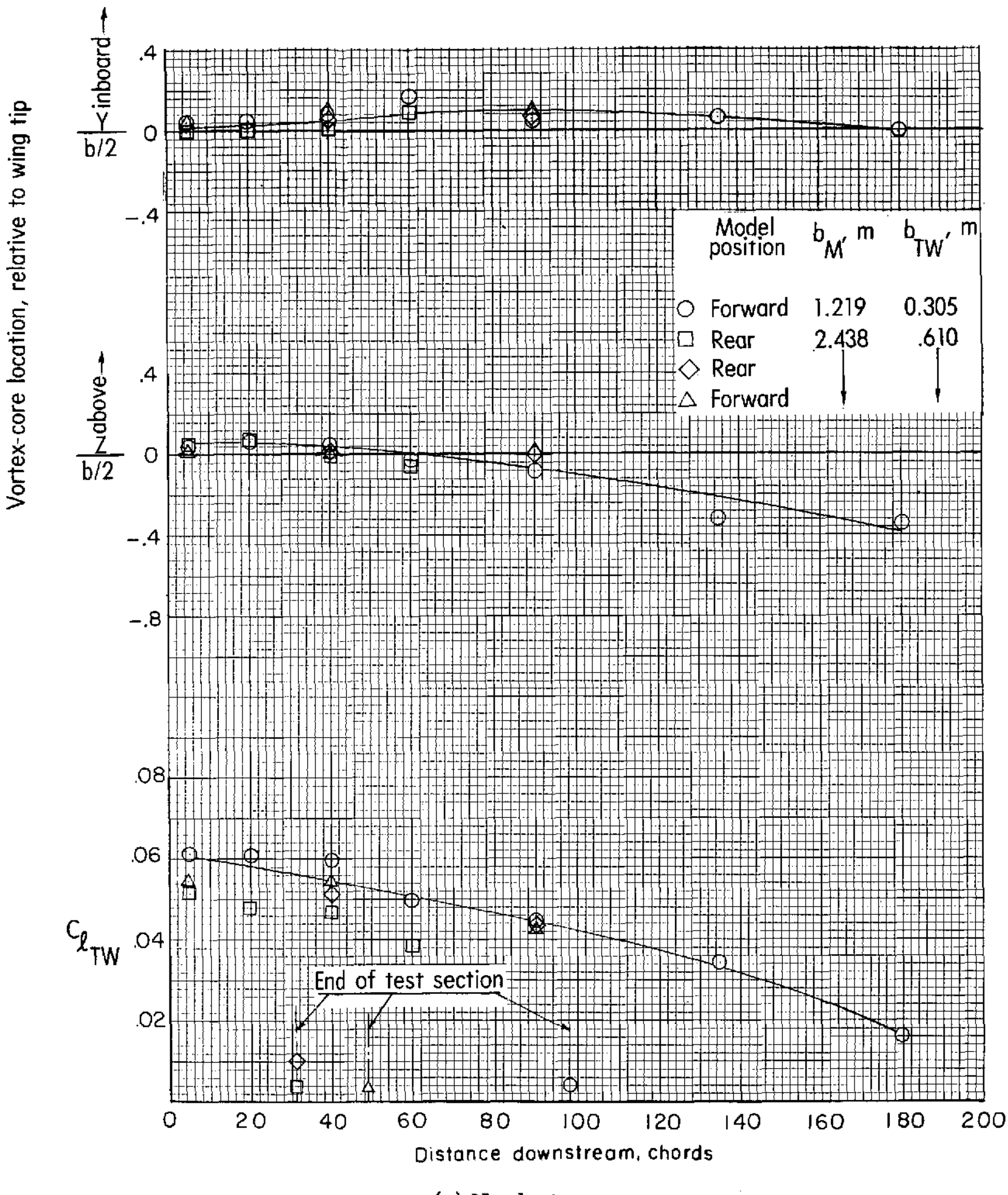
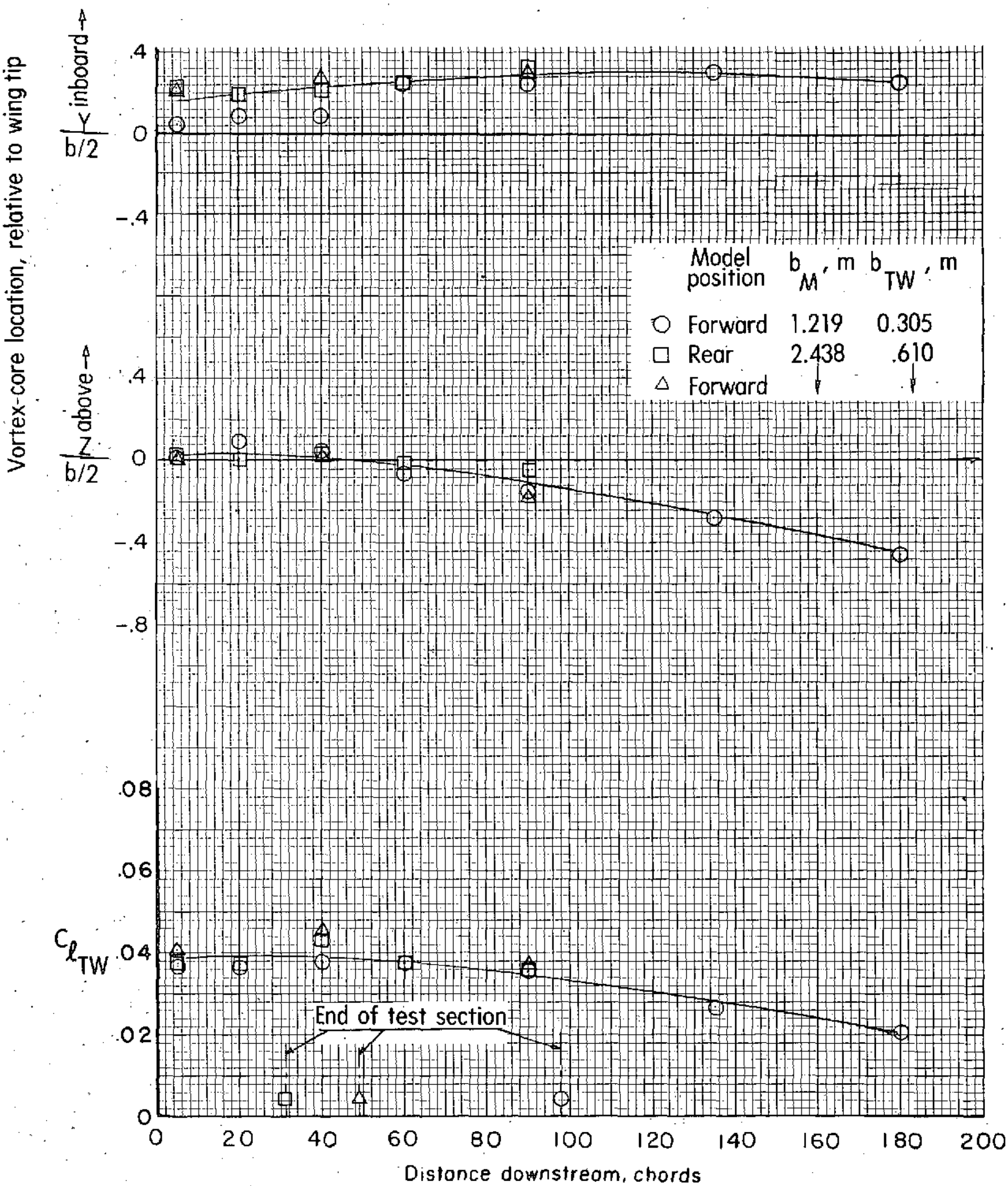


Figure 9.- Effect of midspan spoiler and trailing spline on the longitudinal aerodynamic characteristics of the 2.438-meter-span aspect-ratio-8 model equipped with three-quarter-span single-slotted flap at a flap deflection of 30°.



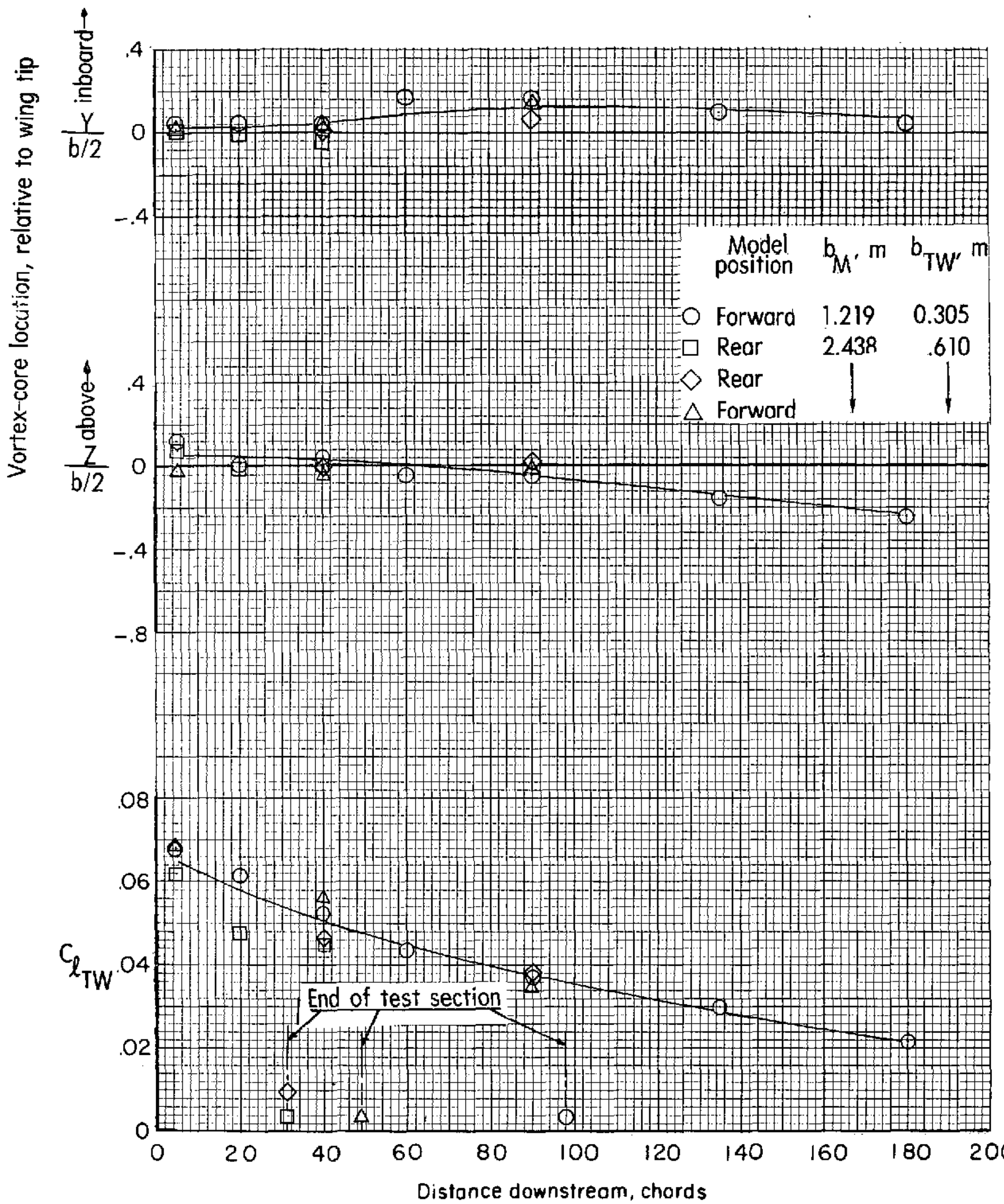
(a) No device.

Figure 10.- Variation of vortex-core location and trailing-wing rolling-moment coefficients with downstream distance behind the aspect-ratio-8 models (C_L = 0.5).



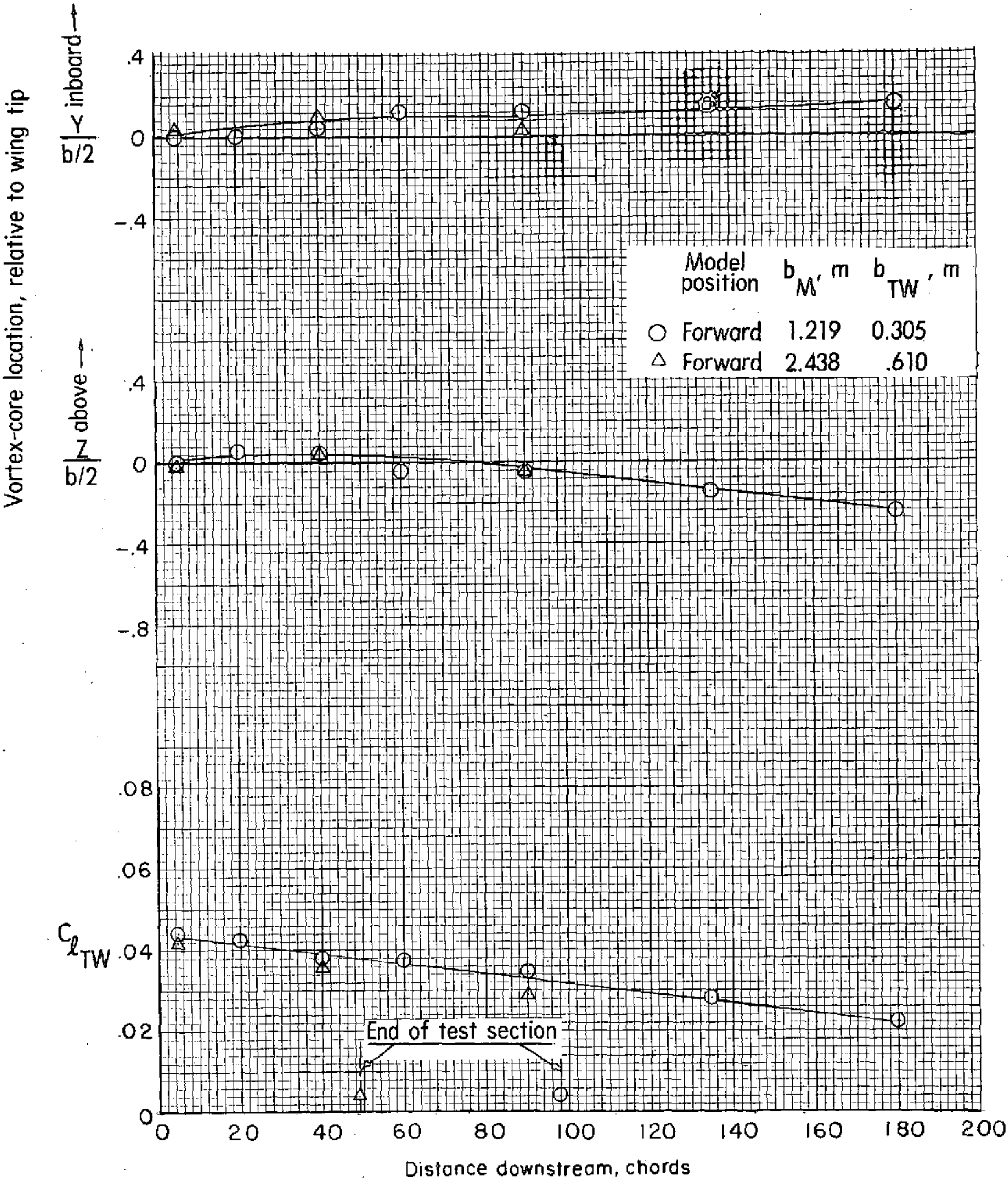
(b) Outboard spoiler.

Figure 10.- Continued.



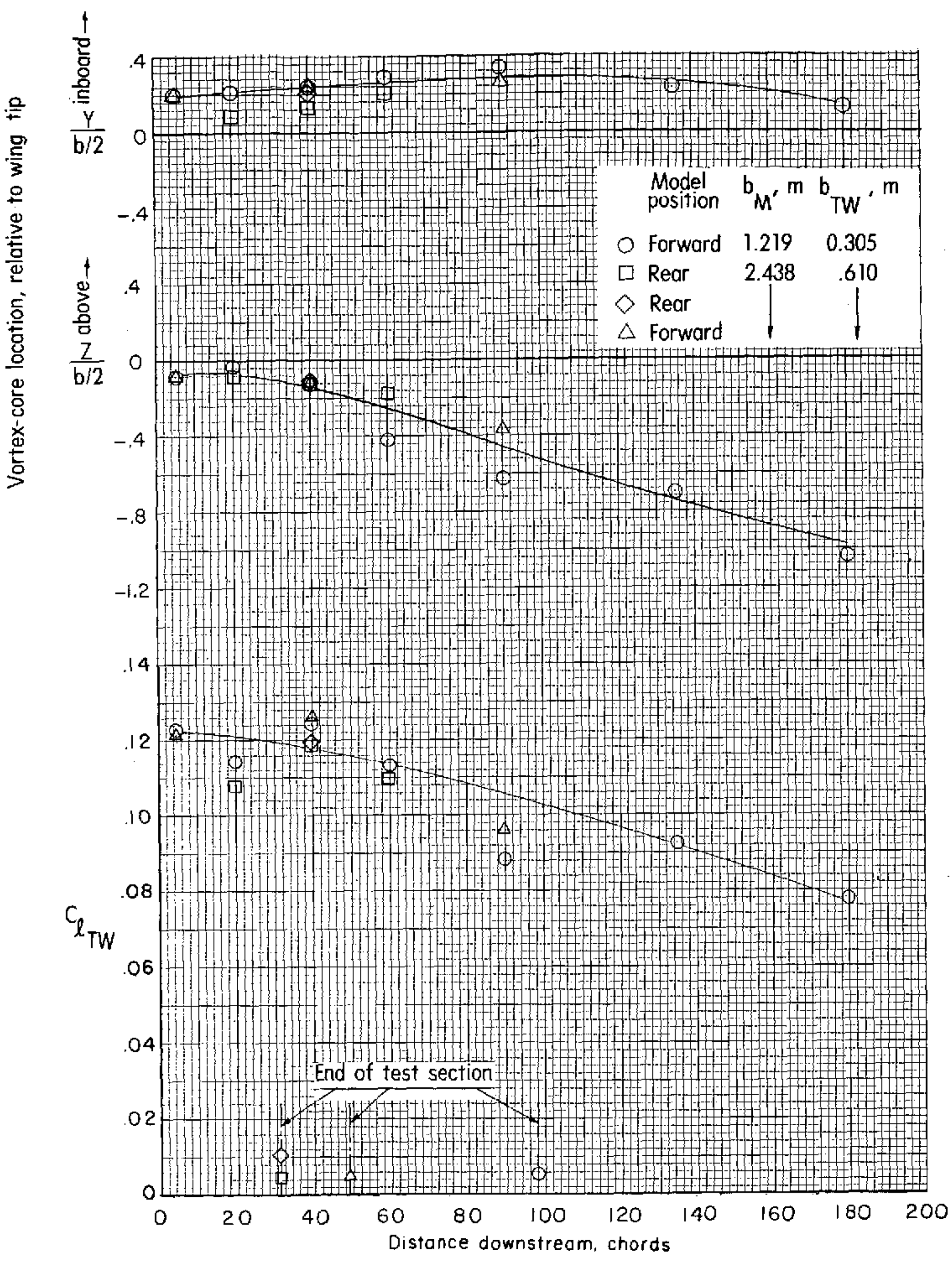
(c) Midspan spoiler.

Figure 10.- Continued.



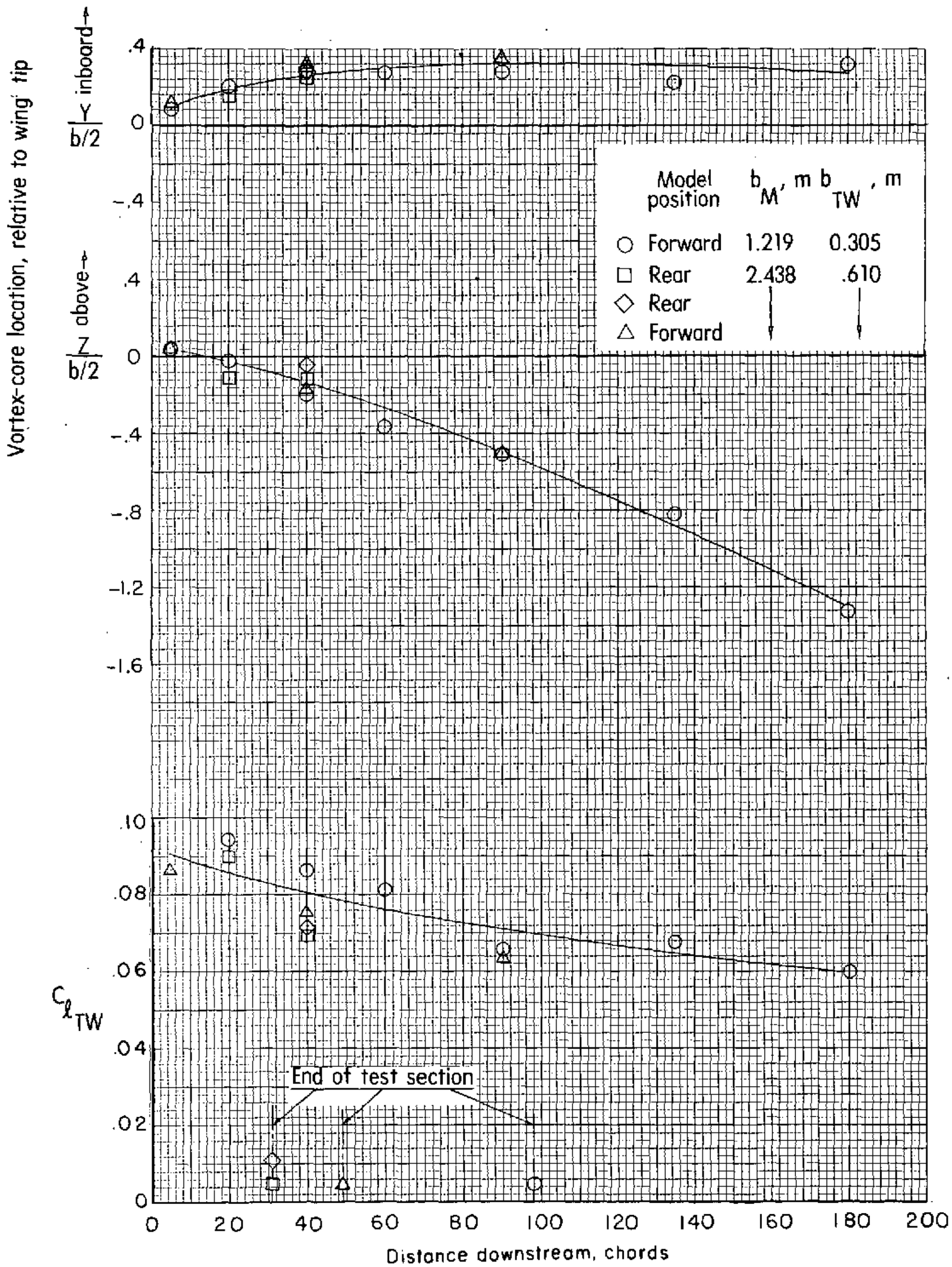
(d) Trailing spline.

Figure 10.- Concluded.



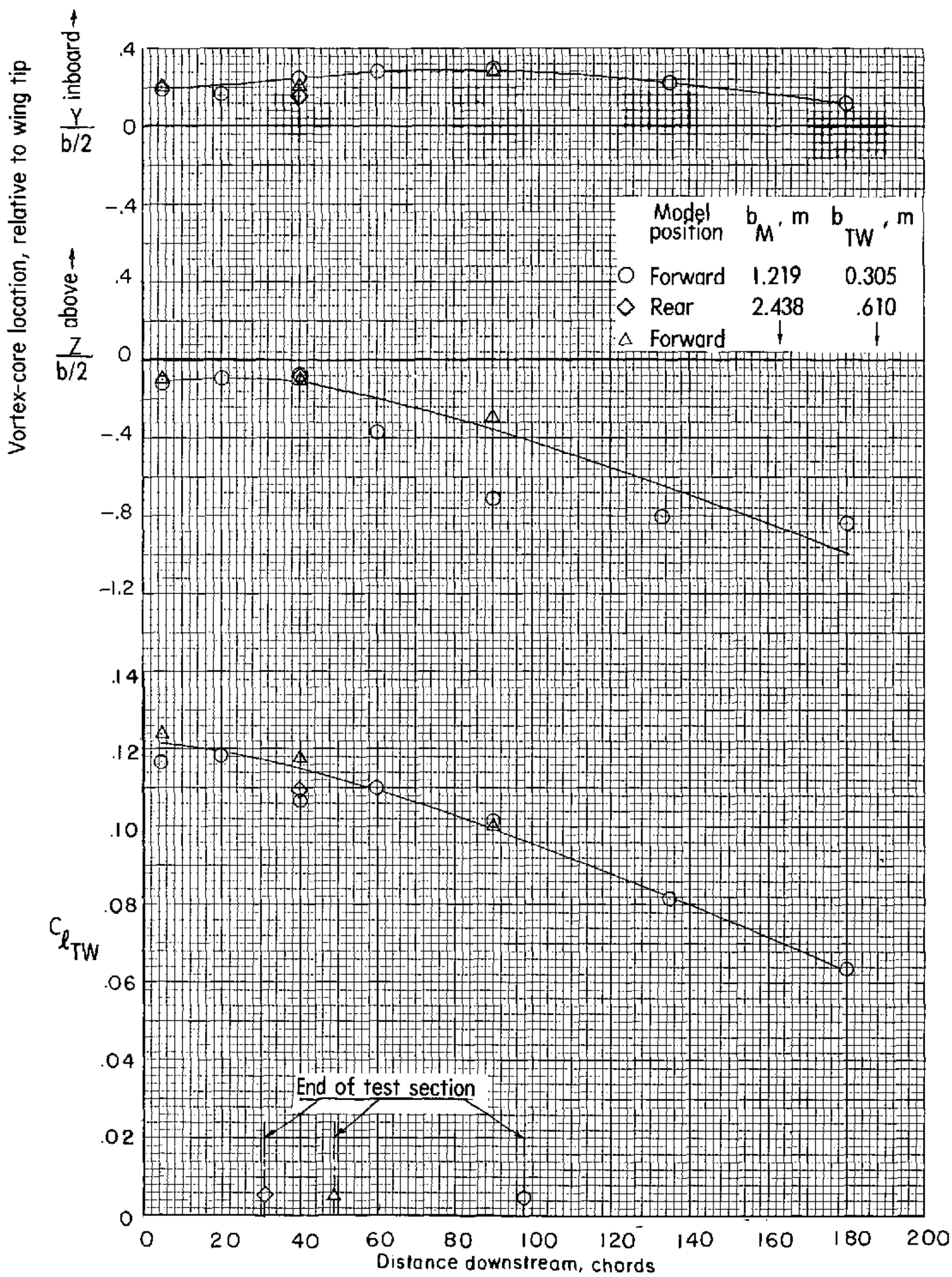
(a) No device.

Figure 11.- Variation of vortex-core location and trailing-wing rolling-moment coefficients with downstream distance behind the aspect-ratio-8 model equipped with three-quarter-span single-slotted flap (with a flap deflection of 30° and at $C_L = 1.25$).



(b) Midspan spoiler.

Figure 11.- Continued.



(c) Trailing spline.

Figure 11.- Concluded.

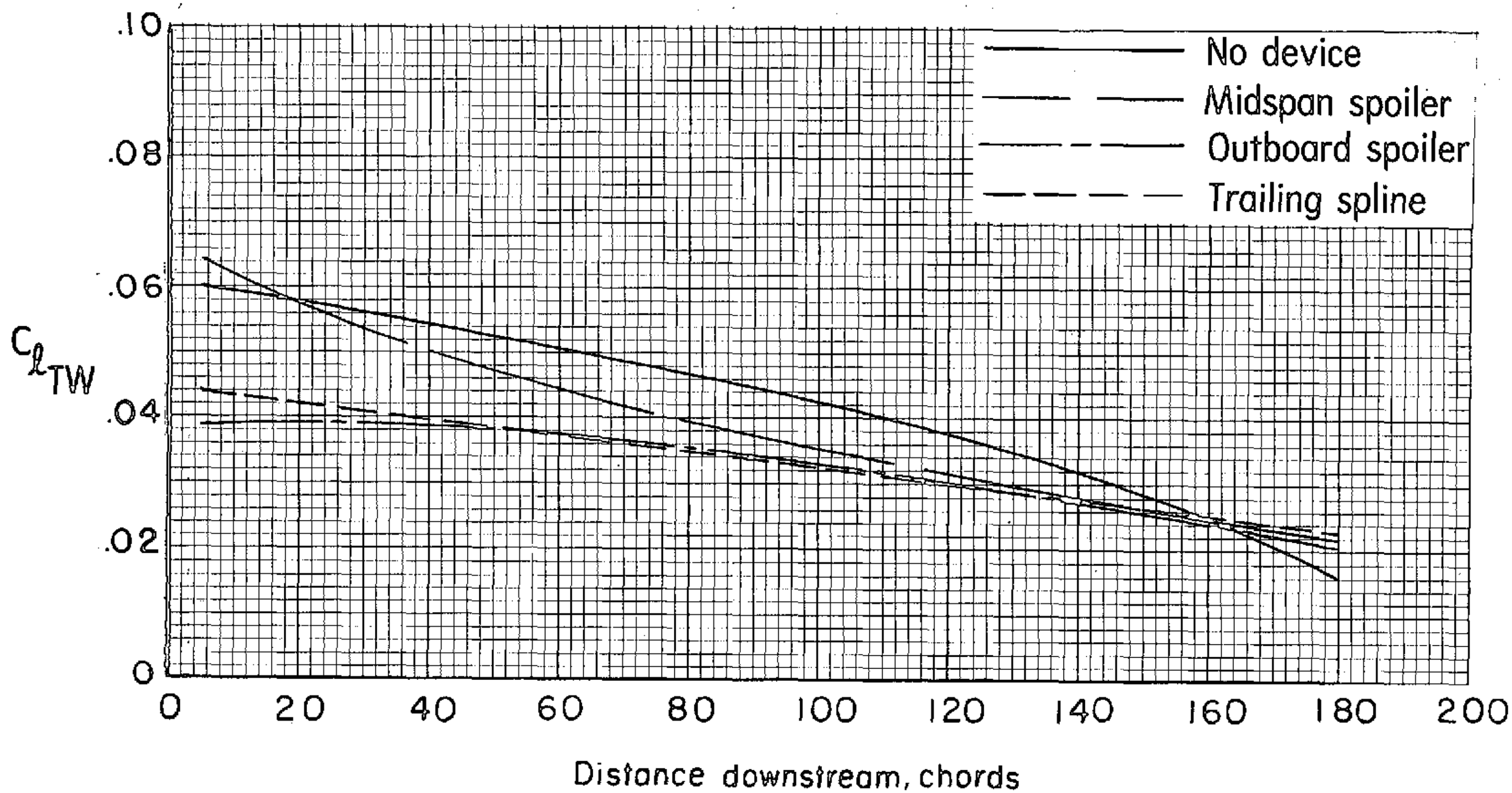


Figure 12.- Variation of trailing-wing rolling-moment coefficients with downstream distance behind the basic model, model with spoilers, and model with splines ($C_L = 0.5$).

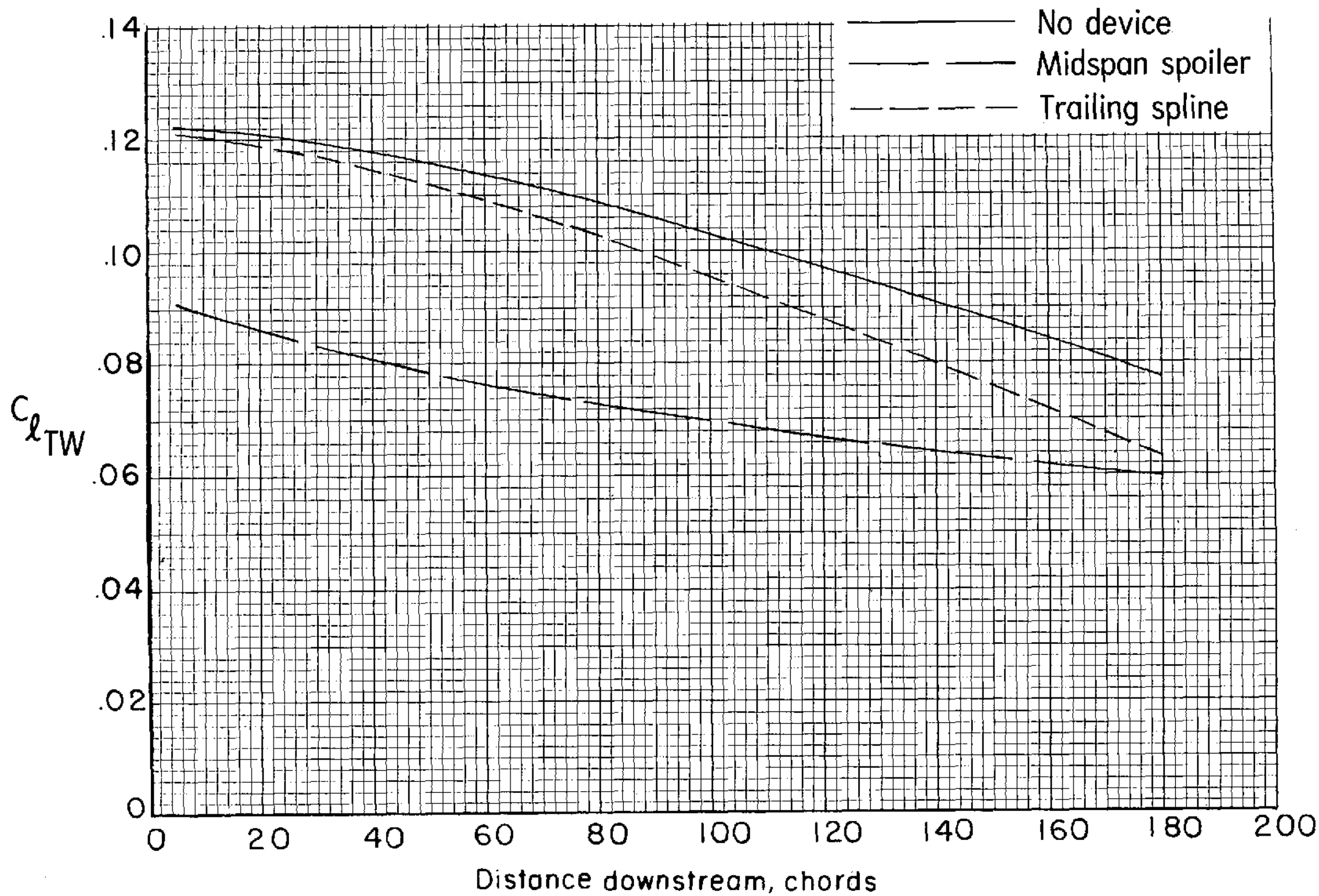


Figure 13.- Variation of trailing-wing rolling-moment coefficients with downstream distance behind the model with flaps, model with flaps and spoilers, and model with flaps and splines ($C_L = 1.25$).

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