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THE DEVELOPMENT AND
USE OF SPOILERS AS VORTEX ATTENUATORS

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SUMMARY

This paper presents the results of groundbased and flight investigations performed at NASA to develop spoilers as trailing vortex alleviation devices. Based on the results obtained in these investigations, it was found that the induced rolling moment on a trailing model can be reduced by spoilers located near the midsemispan of a vortex-generating wing. Substantial reductions in induced rolling moment occur when the spoiler vortex attenuator is located well forward on both unswept and swept wing models. In addition, it was found that existing flight spoilers on the jumbo-jet transport aircraft can be effective as trailing vortex attenuators.

INTRODUCTION

The strong vortex wakes generated by large transport aircraft are a potential hazard to smaller aircraft. NASA is involved in a program of model tests, flight tests, and theoretical studies to determine the feasibility of reducing the hazard by aerodynamic means. This hazard is defined schematically in figure 1. One phase of this program has been devoted to experimental investigations of spoilers as a possible method of trailing vortex attenuation because spoilers can inject turbulence in the wake, and they are also an effective way to alter the span load distribution. This paper briefly covers NASA activity in development of spoilers as vortex attenuators.

SYMBOLS

b	wing span, m
c	wing chord, m
$\bar{c}$	wing mean aerodynamic chord, m
C_L	lift coefficient, $\frac{\text{lift}}{qS_W}$
$C_{L,\text{trim}}$	trimmed lift coefficient
$C_{\ell,TW}$	trailing wing rolling-moment coefficient $= \frac{\text{trailing wing rolling moment}}{qS_{TW}b_{TW}}$
C_m	pitching-moment coefficient $= \frac{\text{pitching moment}}{qS_W\bar{c}_W}$
C_μ	momentum coefficient
4	dynamic pressure, Pa
S	wing area, m^2
V	velocity, m/s
V_j	jet velocity, m/s
V_∞	free-stream velocity, m/s
Y	lateral dimension, m
a	angle of attack, deg
δ_j	jet deflection, deg

Subscripts:

max	maximum
TW	trailing wing model
W	generating model

EARLY SPOILER INVESTIGATIONS

In 1970, the NASA Ames Research Center performed wind-tunnel and flight investigations of a wingtip-mounted spoiler (refs. 1 and 2). The wind-tunnel results shown in figure 2 indicated that a downstream distance of 10 wing chord lengths, the circumferential was reduced because of the spoiler by approximately one-half, while the core diameter was approximately doubled. These results were interpreted as significantly altering the vortex structure in a manner that would contribute to a more rapid dissipation of the vortex and an accompaying reduction in vortex intensity. Subsequent to the wind-tunnel test, wingtip spoilers were mounted on the left wingtip of a Convair 990 aircraft for evaluation in flight. In the flight program, a Learjet 23 airplane was used to probe the vortexes from both the right and left wingtip of the Convair 990. The roll response of the Learjet was used as an index of the intensities of the vortexes. Several short encounters with each vortex were made by the probe aircraft, and the pilot reported that he could tell no difference between the modified and unmodified vortexes from the dynamic response of the aircraft. It was concluded, therefore, that further research was required to determine an effective technique in the use of spoilers for vortex attenuation.

RECENT SPOILER INVESTIGATIONS

In 1971, experimental work was initiated at the NASA Langley Research Center to further investigate spoilers as a possible vortex abatement device. In the first phase of this study, a semispan wing was used in a study to determine the proper location for a spoiler to be installed on the wing to cause the largest apparent alteration to the trailing vortex. The semispan wing was mounted on the Langley tow tank carriage and propelled through a smoke screen, and observations were made of the behavior of the smoke entrained in the vortex. After several hundred observations of the smoke patterns with the spoilers positioned at practically every conceivable location on the wing, it was determined that a spoiler of about 8-percent chord projection located between the 50- and 75-percent spanwise location near the 30-percent chord line would cause the most alteration to the vortex system, and, in general, the observed vortex motion became essentially nonexistent after a very short time. Based on these observations, a wind-tunnel investigation was made using an unswept aspect-ratio-8 wing model with a spoiler having an 8-percent projection located along the 30-percent chord line between the 50- and 75-percent semispan station as shown in figure 3. The three-quarter span flaps used on this model were appended to the wing as is shown in figure 3. Figure 4 is a photograph of the aspect-ratio-8 model mounted in the Langley V/STOL tunnel.

The spoiler effectiveness was evaluated using the trailing model technique to determine the maximum rolling-moment coefficient (fig. 5) induced by the generating model. It can be seen that the spoiler was effective in reducing the induced rolling-moment coefficient on the following model by about 25 percent throughout the range of downstream distances investigated. The complete results of this investigation were reported in reference 3.

Because the prime concern was the vortex-wake problem behind very large transport aircraft, a decision was made to concentrate ground-based studies on the jumbo-jet class of aircraft. Therefore, a 0.03-scale model of a jumbo-jet transport (fig. 6) was used for subsequent tests in the Langley V/STOL tunnel. Results of this investigation are reported in reference 4. Figure 7 is a photograph of the generating aircraft model mounted in the V/STOL tunnel with all landing flaps extended 30°; also shown downstream is the traverse rig for mounting the trailing model.

Two sizes of unswept trailing wing models were used during the investigations (fig. 8). One had a span and aspect ratio equivalent to a small business jet aircraft; the other had the span and aspect ratio equivalent to a medium size jet transport aircraft. These trailing models are referred to on the figures as the small and the large trailing models.

The first spoiler configuration investigated as a vortex attenuator on the generating model was a plain vertical projection spoiler located along the 30-percent chord line between the 50- and 75-percent semispan stations as is shown in figure 9. Figure 10 is a photograph of the spoilers mounted on the wing of the generating model. Figure 11 shows the effect of spoiler projection on the induced rolling-moment coefficient, measured on the small trailing wing model located at 6.74 spans downstream of the generating model. It can be seen that the maximum reduction in rolling moment was achieved with about an 8-percent spoiler projection. Therefore, subsequent tests were made with the spoiler projected to 8 percent.

The effectiveness of the spoilers in reducing the trailing wing rolling-moment coefficient for the two sizes of trailing models downstream of the generating model is shown in figure 12. It can be seen that the induced rolling-moment coefficient on the large trailing model downstream of the generating model was larger than those induced on the small trailing model. The reduction in induced rolling-moment coefficient on the small trailing model was about 35 to 40 percent over the range of downstream distances investigated; whereas, the reduction in induced rolling-moment coefficient on the large model was on the order of 15 to 25 percent.

Data obtained in the Hydronautics, Inc., water towing tank on the generating model with and without spoilers is shown in figure 13. This facility allows for data to be taken at a greater downstream distance than can be obtained in the V/STOL tunnel. Even though the magnitude of the measured trailing wing rolling-moment coefficients does not agree with those obtained in the V/STOL tunnel, the trends do agree, and the effectiveness of the spoiler as a vortex attenuator is substantiated over the extended downstream range available in the towing tank.

A jet spoiler was also investigated (fig. 14) on the generating model. Holes were drilled into a wing pressure chamber at various angles to the wing upper surface so that various jet-sheet angles could be investigated. In this investigation it was found that when the jet sheet was directed vertically ($\delta_j = 90^\circ$) or inclined forward ($6_j = 120^\circ$), at relatively low values of C_μ the jet spoiler was effective in reducing the induced trailing wing rolling moments on the small trailing model. When the jet sheet was inclined to the rear ($6_j = 60^\circ$ or $6_j = 75^\circ$), the induced rolling moments were not reduced until much larger values of C_μ were reached. A possible reason for this is shown by the data in figure 15. It can be seen that for the vertical- and forward-inclined jet spoiler ($\delta_j = 90^\circ$ and $\delta_j = 120^\circ$) at a C_μ value of 0.05, there is a reduction of lift-curve slope generally associated with the separated region that is expected aft of a forward-located spoiler. When the jet was inclined rearward, there was entrainment of the flow, and no extensive separation region was noted. The jet spoiler in this case acted similarly to a boundary-layer control device.

Even though the spoiler concepts discussed so far did show promise as possible vortex attenuators on the full-scale airplane, their use would require extensive modifications to the airplane. It became apparent that the normal flight spoilers already on the airplane should be studied as possible vortex attenuators. Therefore, exploratory wind-tunnel tests were made in the V/STOL tunnel during March 1975 using wooden wedges to represent the various of the flight spoilers noted on figure 16. These exploratory results were encouraging; therefore, the model wing was modified so that the flight spoilers would be more representative of those on the full-scale transports. Over the section of the wing immediately forward of the outboard flaps, spoilers were constructed that would operate similarly to the actual flight spoilers--when retracted, the spoilers made the contours of the upper surface of the wing and when deflected, a large gap was formed forward of the flap. The spoiler segments identified on figure 16 as 1, 2, 3, and 4 were investigated in the following combinations: 1 and 2 (fig. 17); 2 and 3 (fig. 18); 3 and 4 (fig. 19); and 1 and 4 (fig. 20).

The results obtained for these various combinations of flight spoilers are presented in figure 21. (Complete test results are available in ref. 5.) It can be seen that with either of these various combinations of flight spoiler segments deflected to 45°, there was a large decrease in the trailing rolling-moment coefficient induced on the small trailing wing model. Two of these configurations (1 and 2, and 1 and 4) were investigated over a spoiler deflectio range. The results shown in figure 22 indicate that essentially all the spoiler effectiveness was obtained at a deflection angle of about 30°.

Data obtained in the V/STOL tunnel using the large trailing model (fig. 23) indicate that the induced rolling-moment coefficient is attenuated, however, to a lesser extent than was noted for the smaller trailing model. Data obtained in the Hydronautics, Inc., water towing tank with the small trailing model (fig. 24) confirmed the foregoing results and also indicated that the large reduction in induced rolling-moment coefficient on the small trailing model was also realized at much greater downstream distance than was obtainable in the Langley V/STOL tunnel.

Tests were also made in the Langley Vortex Research Facility of the various flight spoilers as vortex attenuators on a genarating model, and the results (fig. 25) essentially agree with those obtained in both the Langley V/STOL tunnel and the Hydronautics, Inc., water tank facility.

As a result of the findings in the ground-based facilities, a flight program was made at the Hugh L. Dryden Flight Research Center that used the existing flight spoilers on a NASA-owned B-747 aircraft as the vortex attenuating device. A T-37 aircraft is used to penetrate the trailing vortex. Penetrations behind the B-747 airplane in its landing configuration were limited to about 13 km (7 n, mi.), with appropriate deflection of the 3-747 flight spoilers, penetration as close as about 4 km (2 n. mi.) were made. These flights results (ref. 6) have verified the trends obtained in the ground-based facilities.

CONCLUDING REMARKS

Results obtained in these investigations showed that the induced rolling moment on a trailing model can be reduced by spoilers located near the midsemispan of a wing. Substantial reductions in induced rolling moment occur when the spoiler vortex attenuator is located well forward on both unswept and swept wing models. In addition, it was found that the existing flight spoilers on the jumbo-jet transport aircraft model are effective as trailing vortex attenuators.

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1. Corsiglia, Victor R.; Jacobsen, Robert A.; and Chigier, Norman: An Experimental Investigation of Trailing Vortices Behind a Wing With a Vortex Dissipator. Aircraft Wake Turbulence and Its Detection, Plenum Press, Inc., 1971, pp. 229-242.
2. Dunham, R. Earl, Jr.; Verstynen, Harry A., Jr.; and Benner, Margaret S.: Progress Report on Wing Trailing Vortex Studies. NASA SP-270, 1971, pp. 101-113.
3. Croom, Delwin R.: 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 TM-X-3166, 1975.
4. Croom, Delwin R.; and Dunham, R. Earl, Jr.: Low-Speed Wind-Tunnel Investigation of Span Load Alteration, Forward-Located Spoilers, and Splines as Trailing-Vortex Hazard Alleviation Devices on a Transport Aircraft Model. NASA TN D-8133, 1975.
5. Croom, Delwin R.: Low-Speed Wind-Tunnel Investigation of Various Segments of Flight Spoilers as Trailing-Vortex-Alleviation Devices on a Transport Aircraft Model. NASA TN D-8162, 1976.
6. Barber, Marvin R.; Hastings, Earl C., Jr.; Champine, Robert A.; and Tymczyszyn, Joseph J.: Vortex Attenuation Flight Experiments. NASA SP-409, 1977.

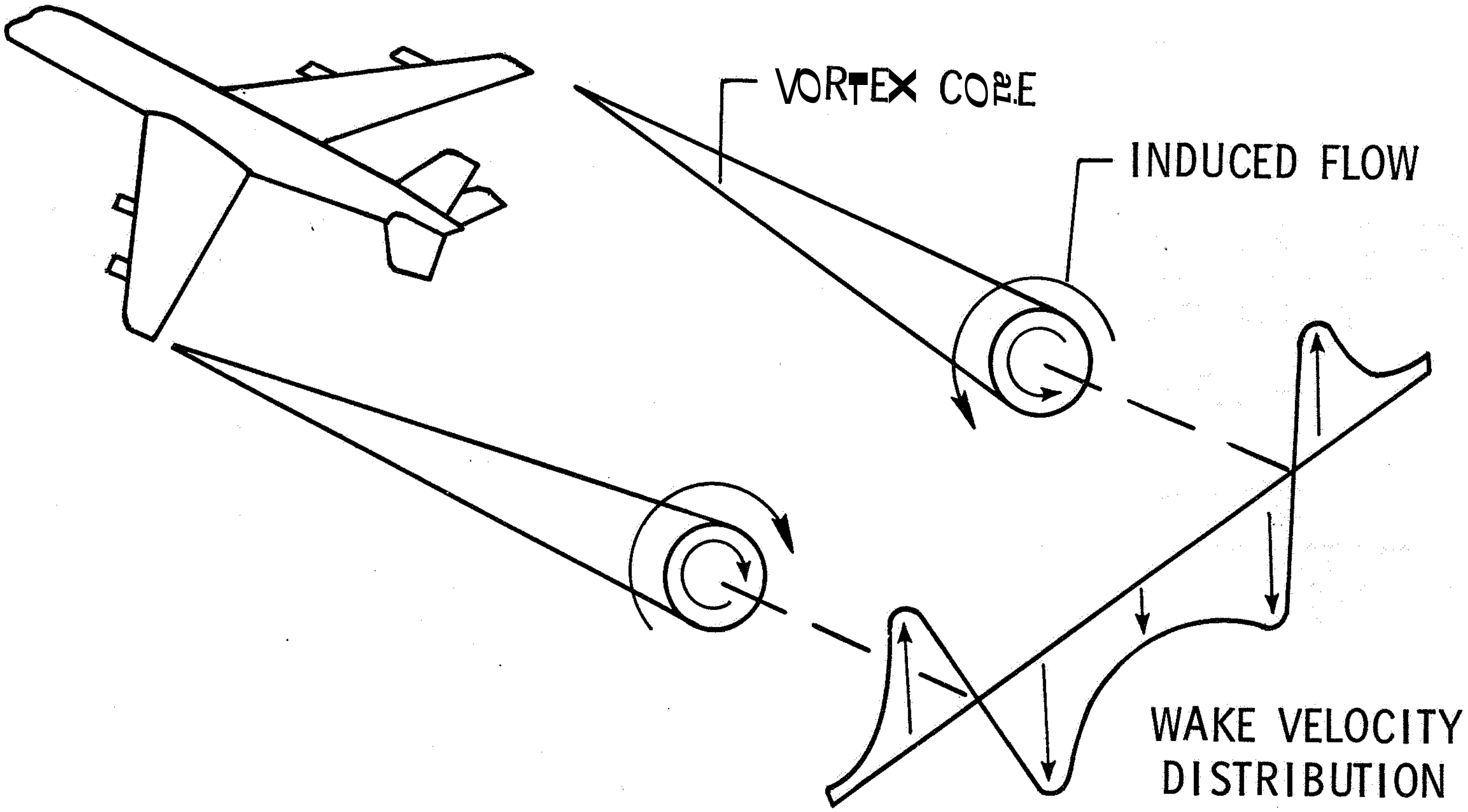


Figure 1 —Aircraft vortex wake hazard

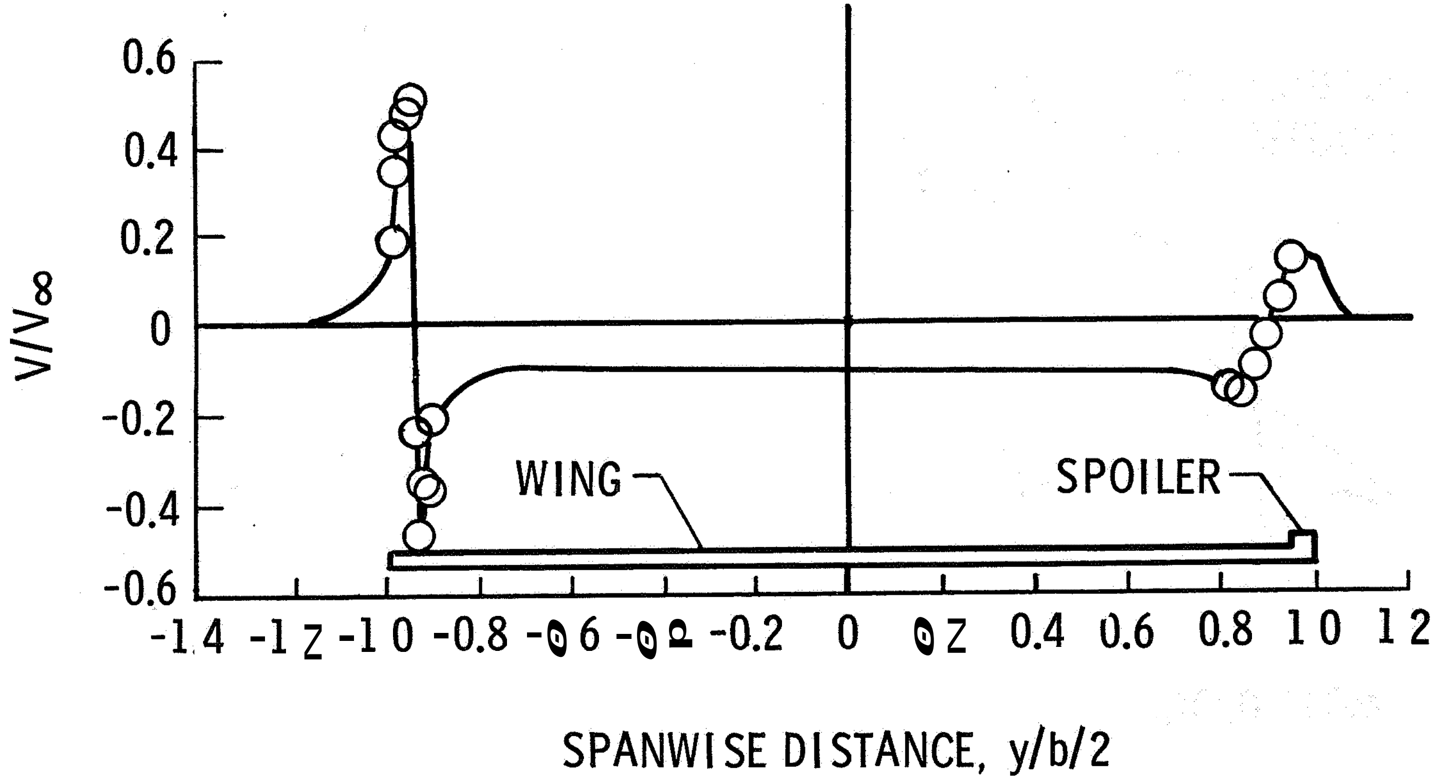


Figure 2.--Tangential velocity components for trailing vortex (left tip) and dissipated vortex (right tip). x/c = 10.

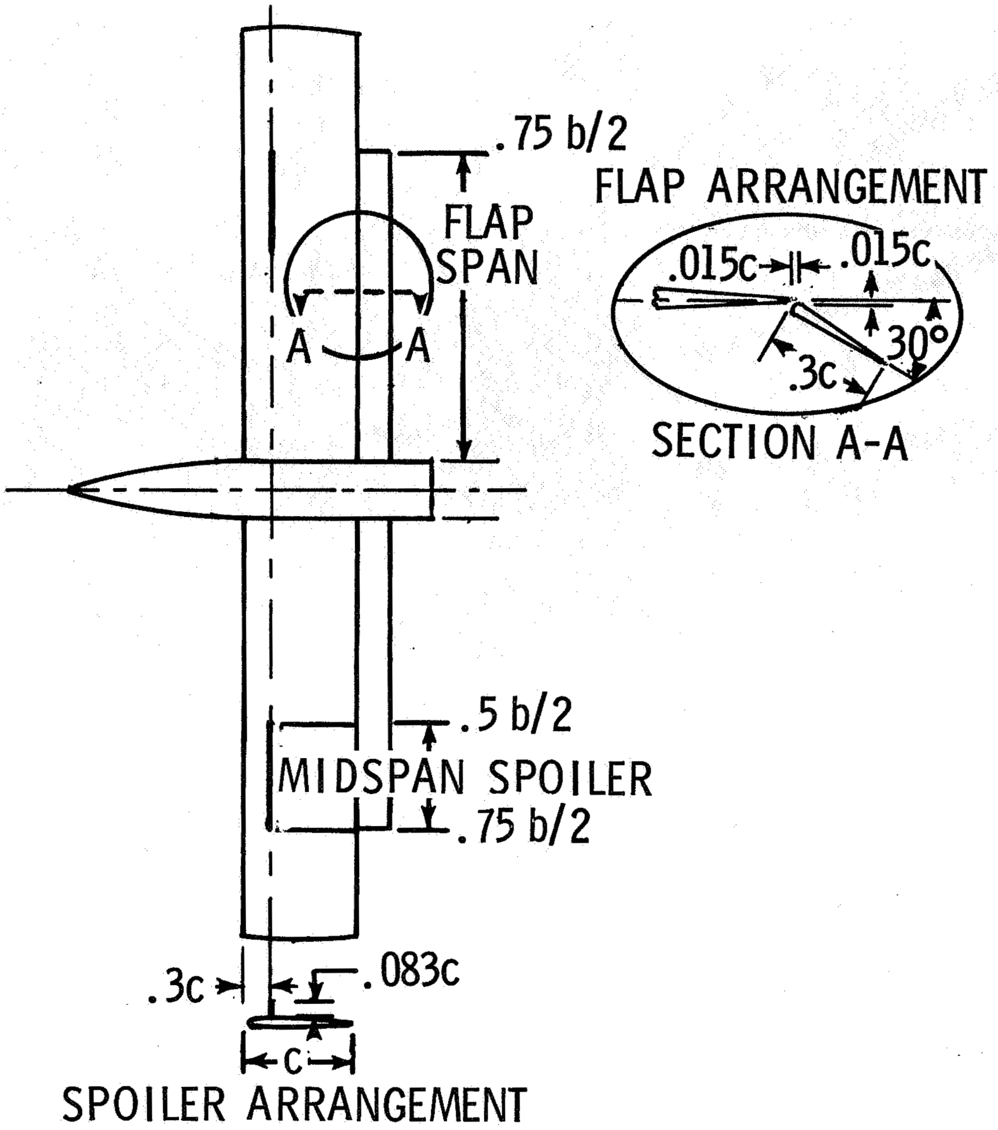


Figure 3.--Sketch of aspect-ratio-8 models.

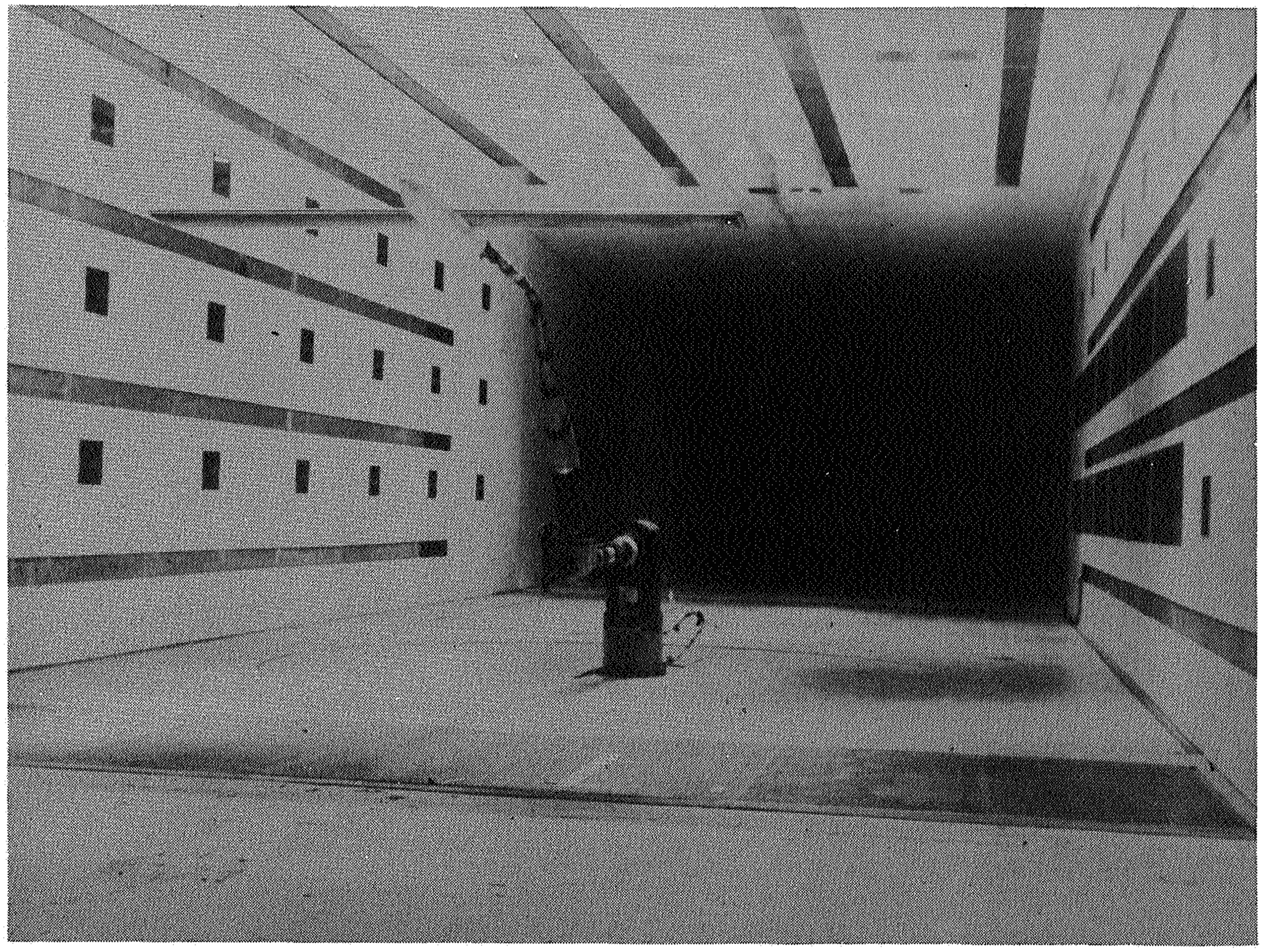


Figure 4.--Aspect-ratio-8 model in Langley V/STOL tunnel.

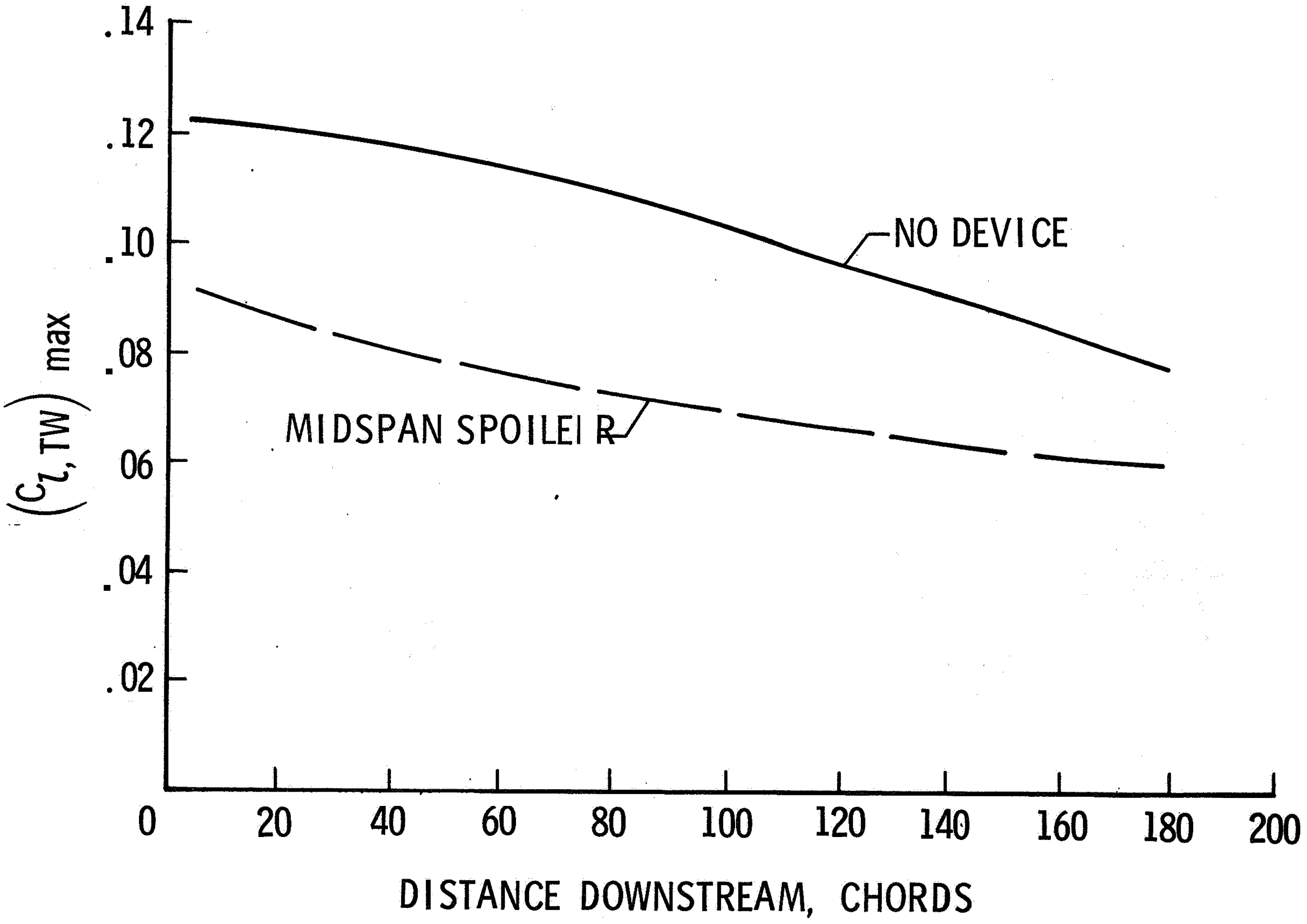


Figure VI -Effect of spoiler on aspect-ratio-8 model. $C_L = 1.25$; $b_{TW}/b = 0.25$.

WING	
SPAN, m	1.79
MEAN AERODYNAMIC CHORD, m	0.25
ROOT CHORD, m	0.497
TIP CHORD, m	0.121
SWEEPBACK AT QUARTER CHORD, deg	37.5
AREA, m^2	0.460
ASPECT RATIO	6.96
FUSELAGE	
LENGTH, m	2.06
HORIZONTAL TAIL	
SPAN, m	0.664
AREA, m^2	0.123
ASPECT RATIO	3.6

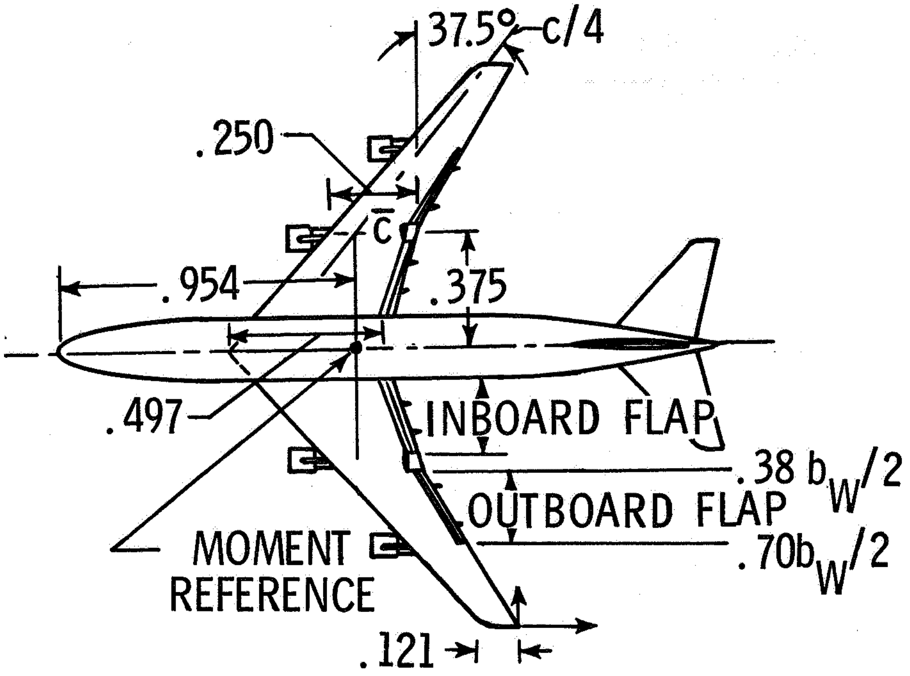


Figure 6 --Plan view of transport aircraft model.

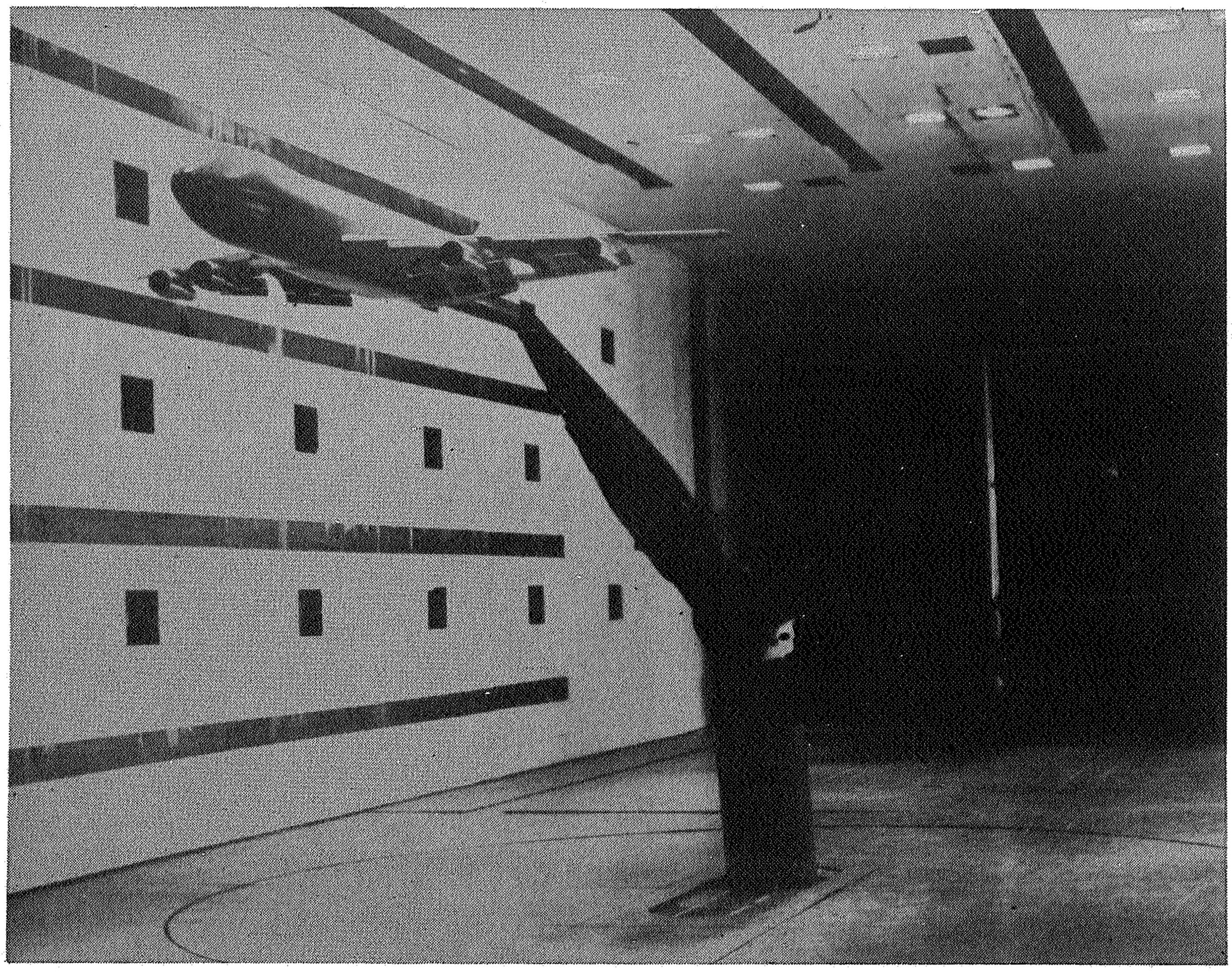
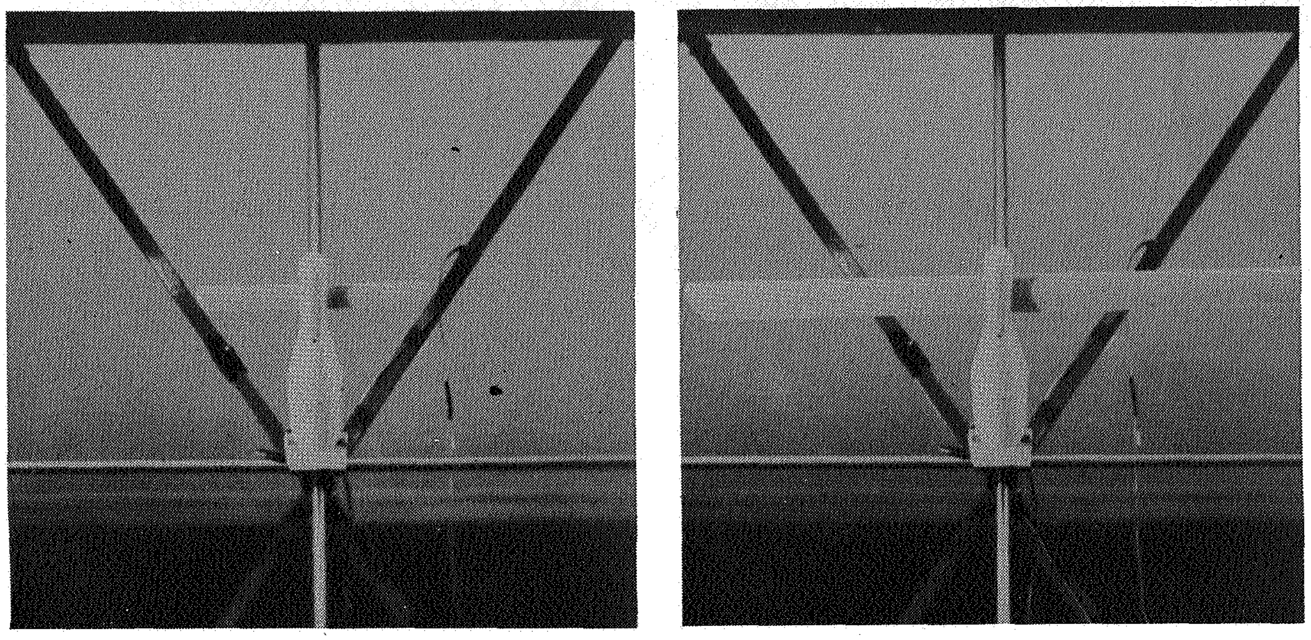


Figure 7.--Transport model with flap configuration 30°/30° in V/STOL tunnel.

AREA, m^2	0.0199	AREA, m^2	0.0845
SPAN, m	.326	SPAN, m	.853
CHORD, m	.061	CHORD, m	.099
ASPECT RATIO	5.45	ASPECT RATIO	8.70



SMALL TRAILING MODEL

LARGE TRAILING MODEL

Figure 8.--Unswept trailing wing models on traverse mechanism.

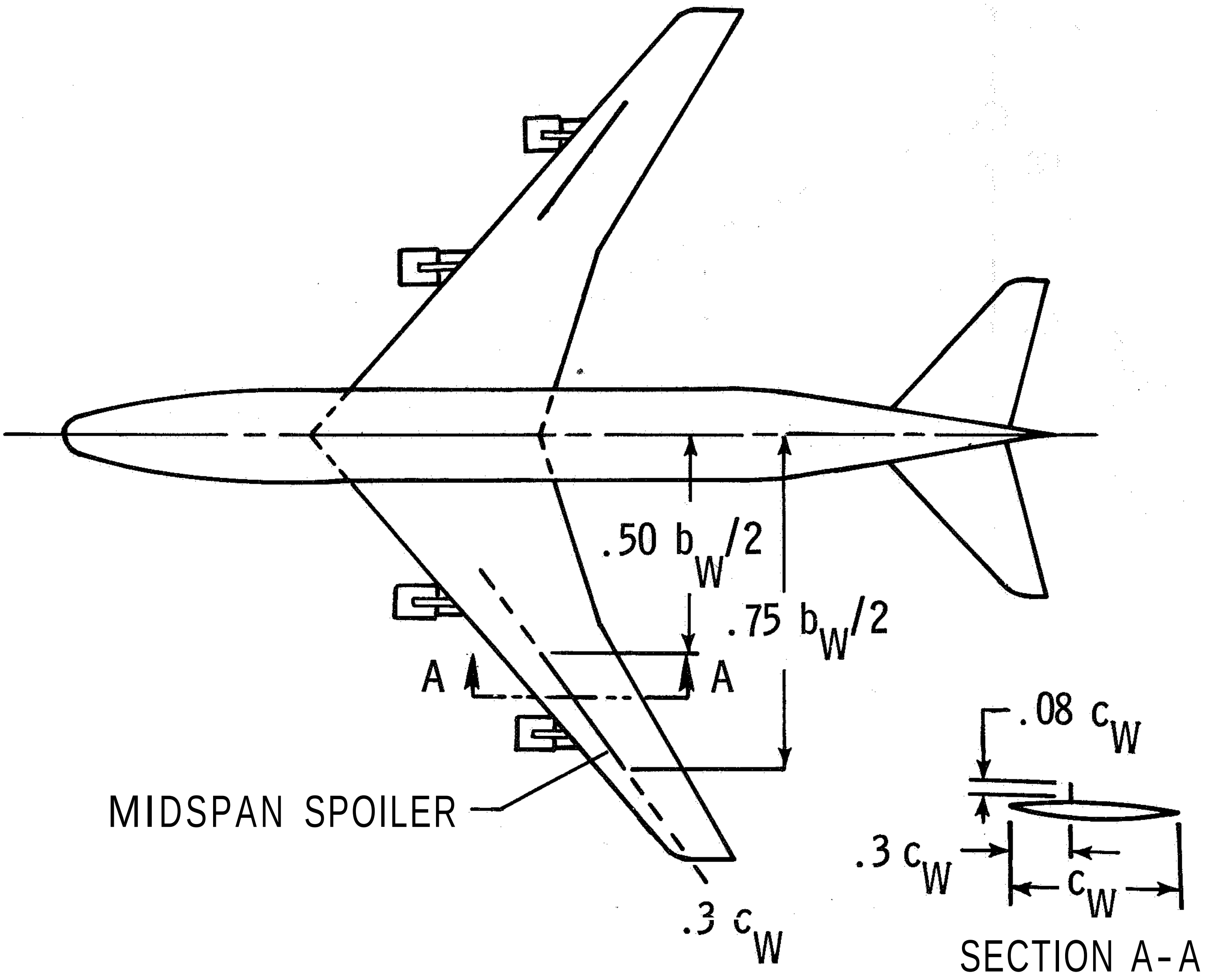


Figure 9.––Midspan spoiler configuration details.

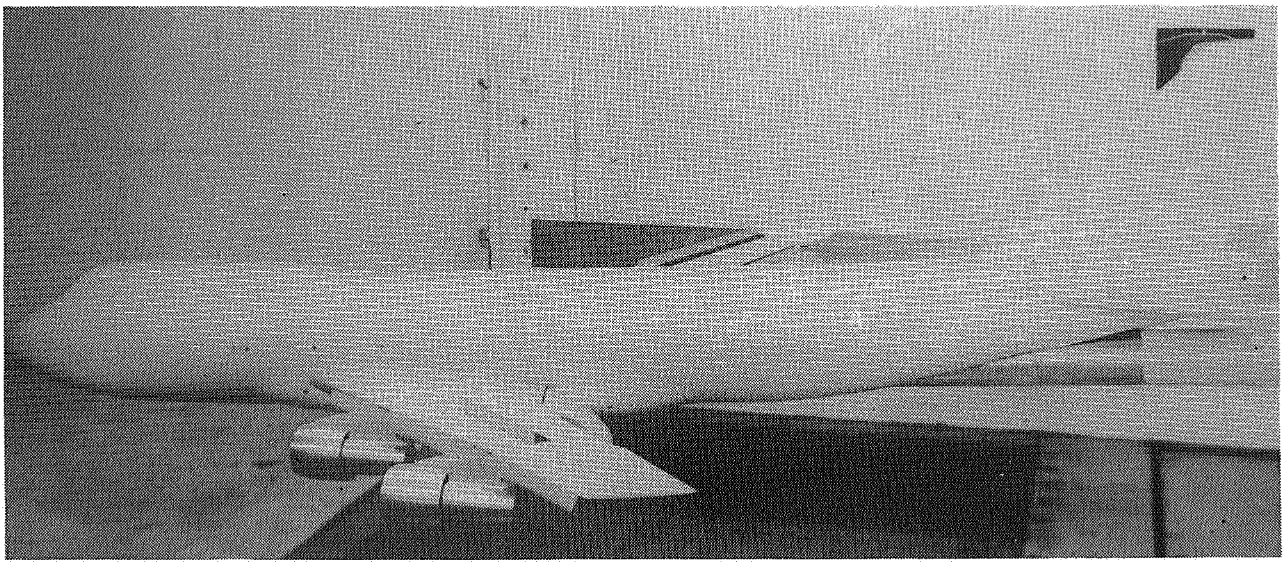


Figure 10.––Midspan spoiler on transport model.

Figure 11,--Transport model with forward-located midspan spoiler. $C_{L,trim} = 1.2$; 6.74 spans downstream.

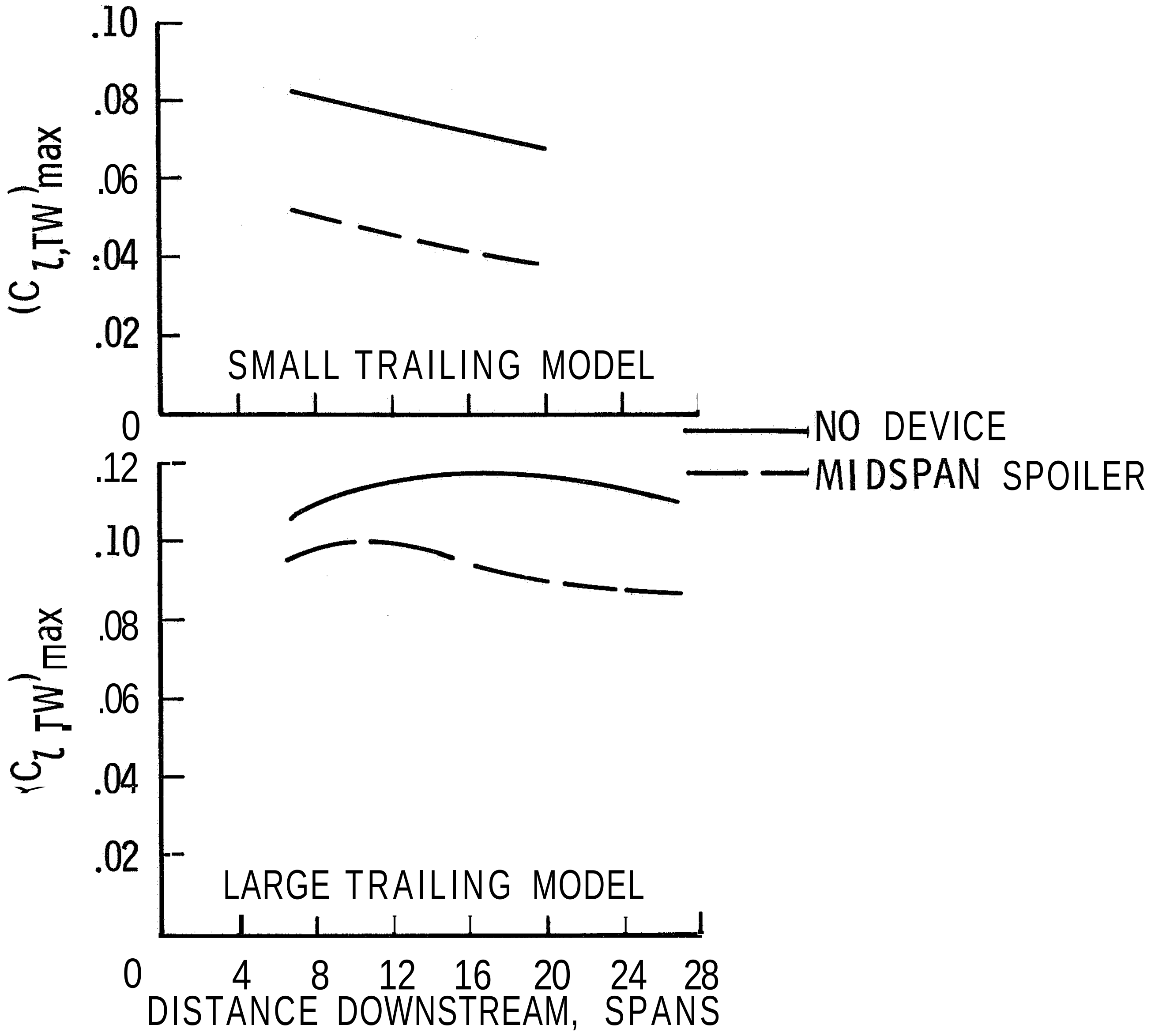


Figure 12.--Variation of trailing wing, rolling-moment coefficient with distance downstream from transport model--V/STOL tunnel. Midspan spoiler; $C_{L,trim}$ = 1.2.

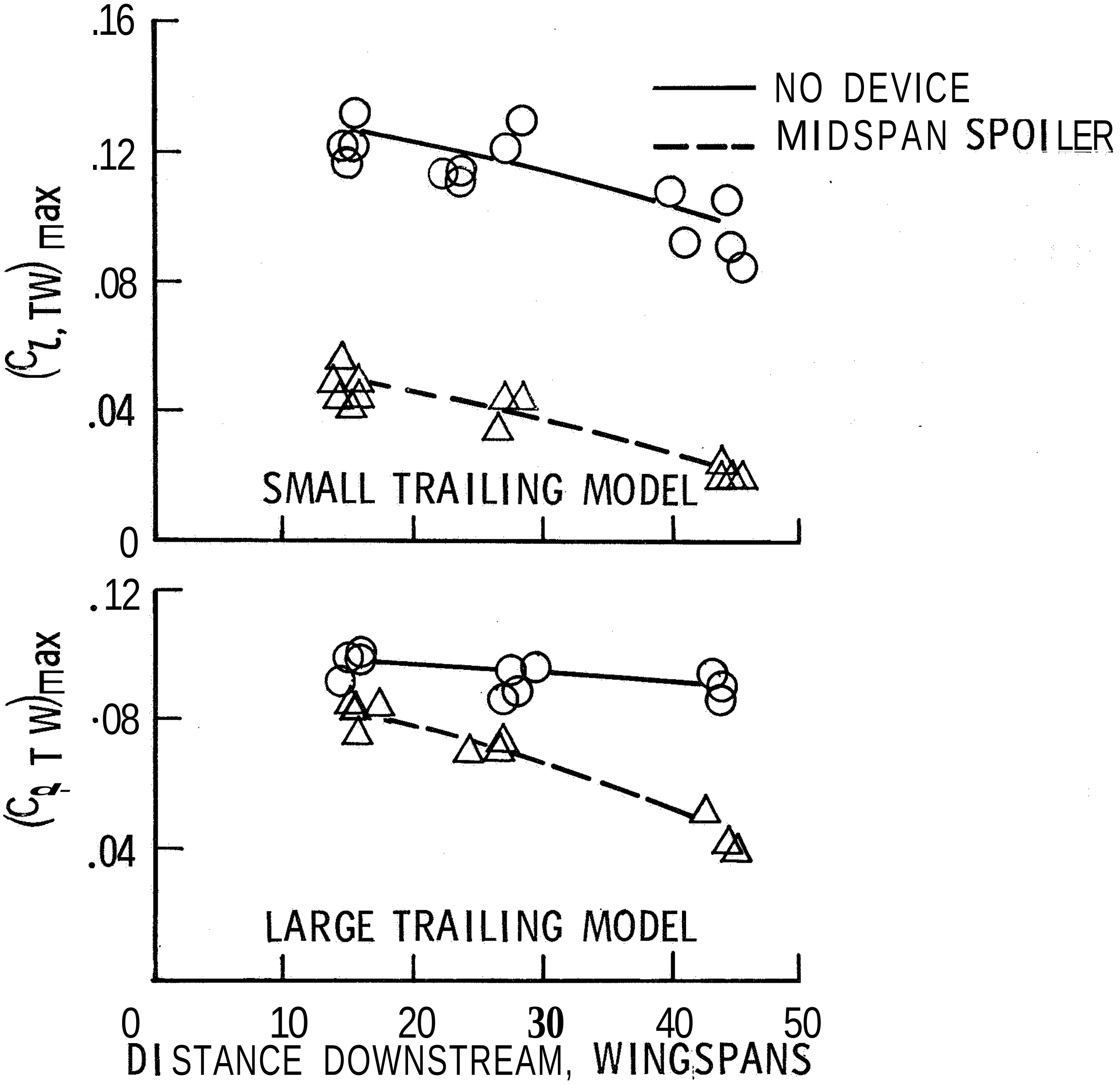


Figure 13.--Variation of trailing wing, rolling-moment coefficient with distance downstream from transport model--water tank. Midspan spoiler; $C_{L,trim} = 1.2$.

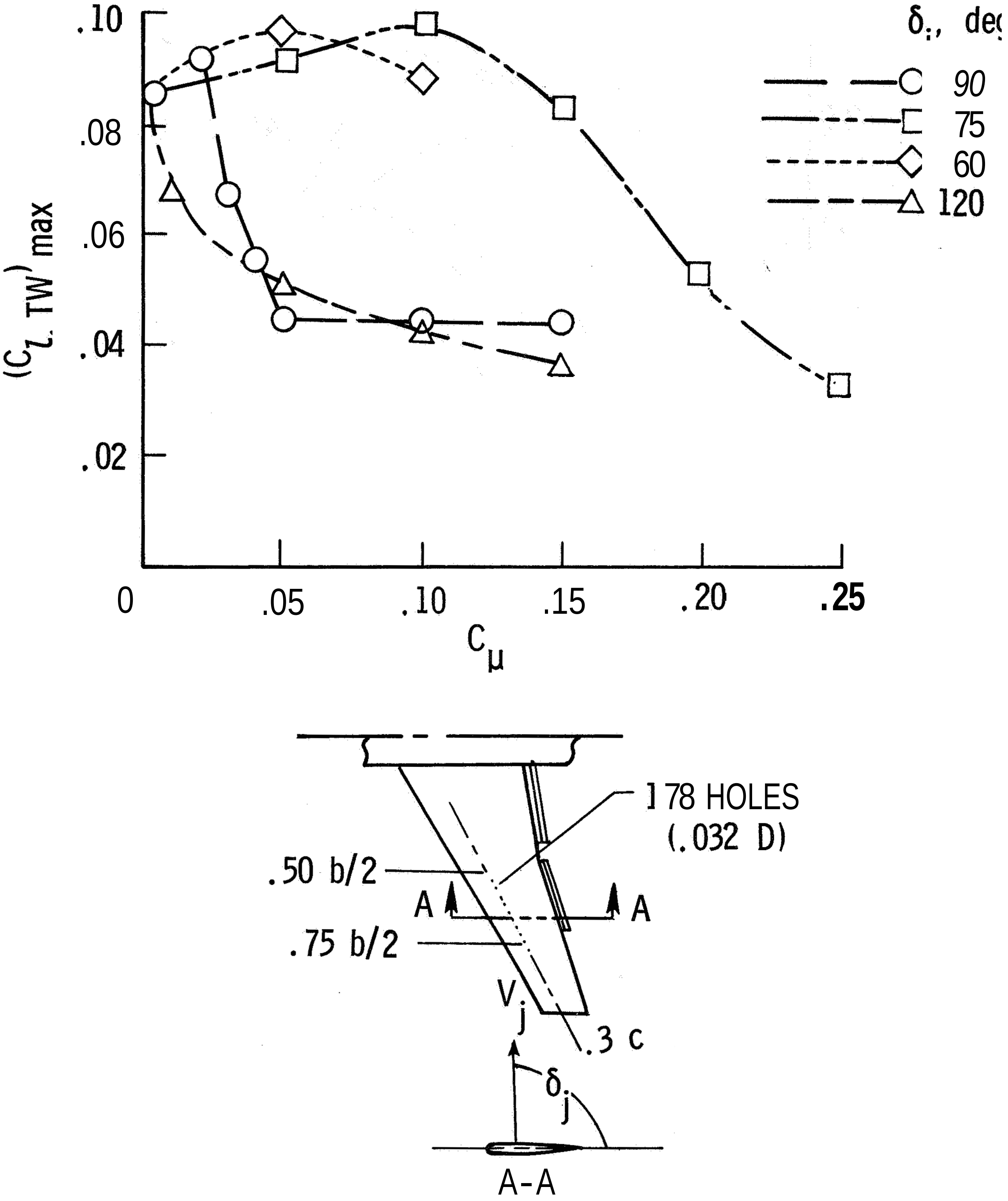


Figure 14.--Transport model with jet spoiler, small trailing wing 6.74 spans downstream. $C_{L,trim} = 1.2$; $C_M = 0$.

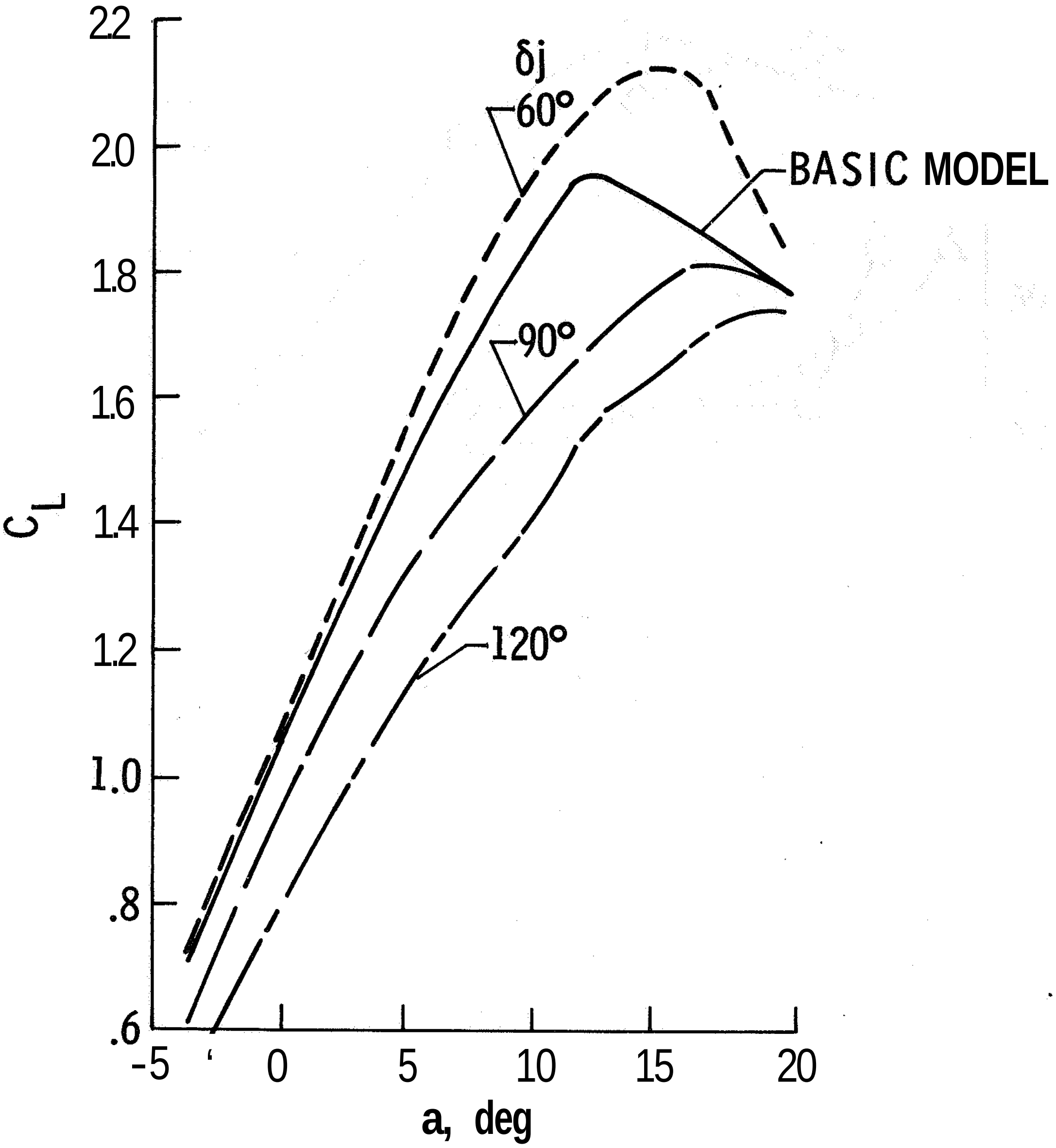


Figure 15.--Transport **model** with jet spoiler, C = 0.05.

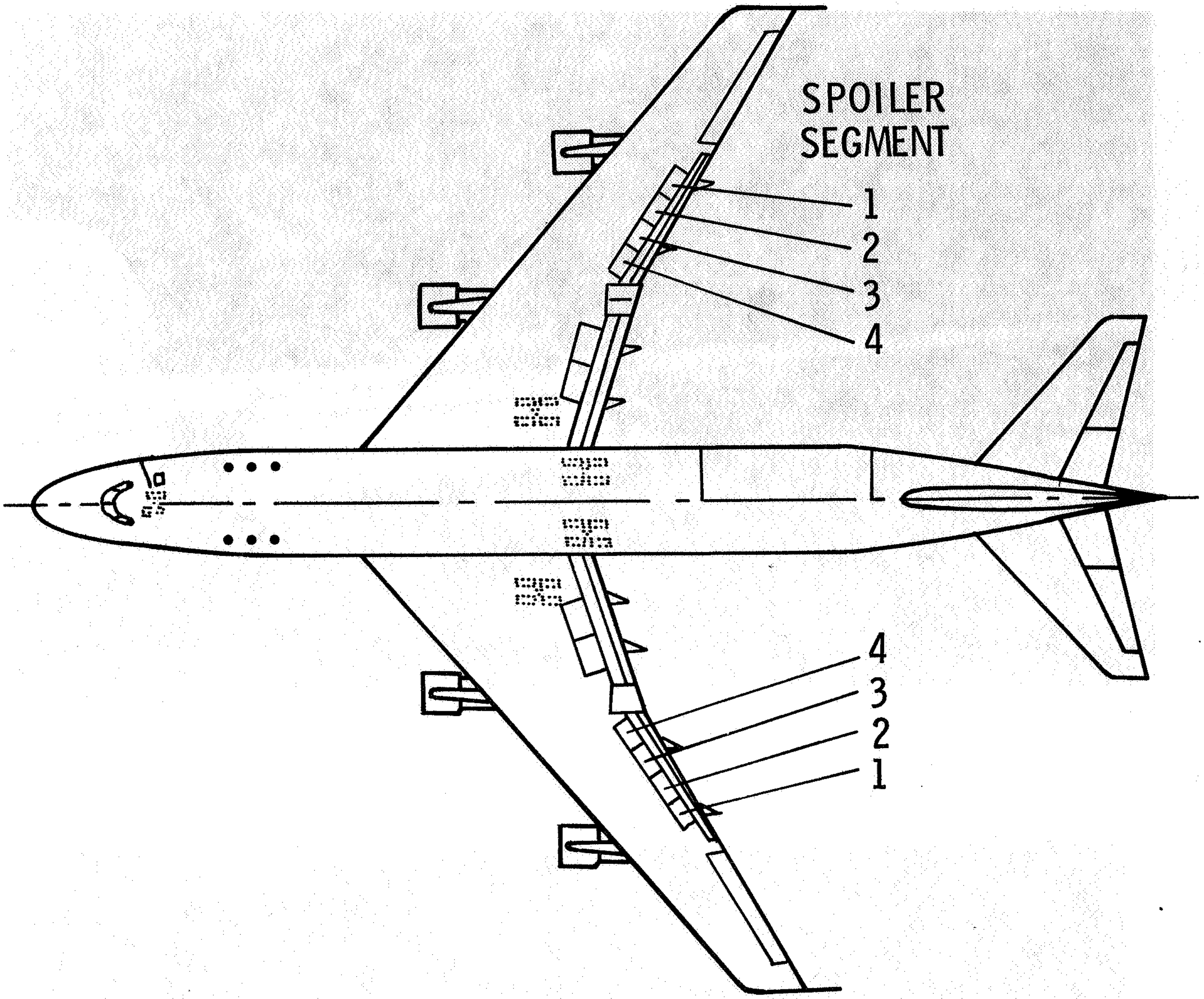


Figure 16.--Flight spoilers on the B-747 model.

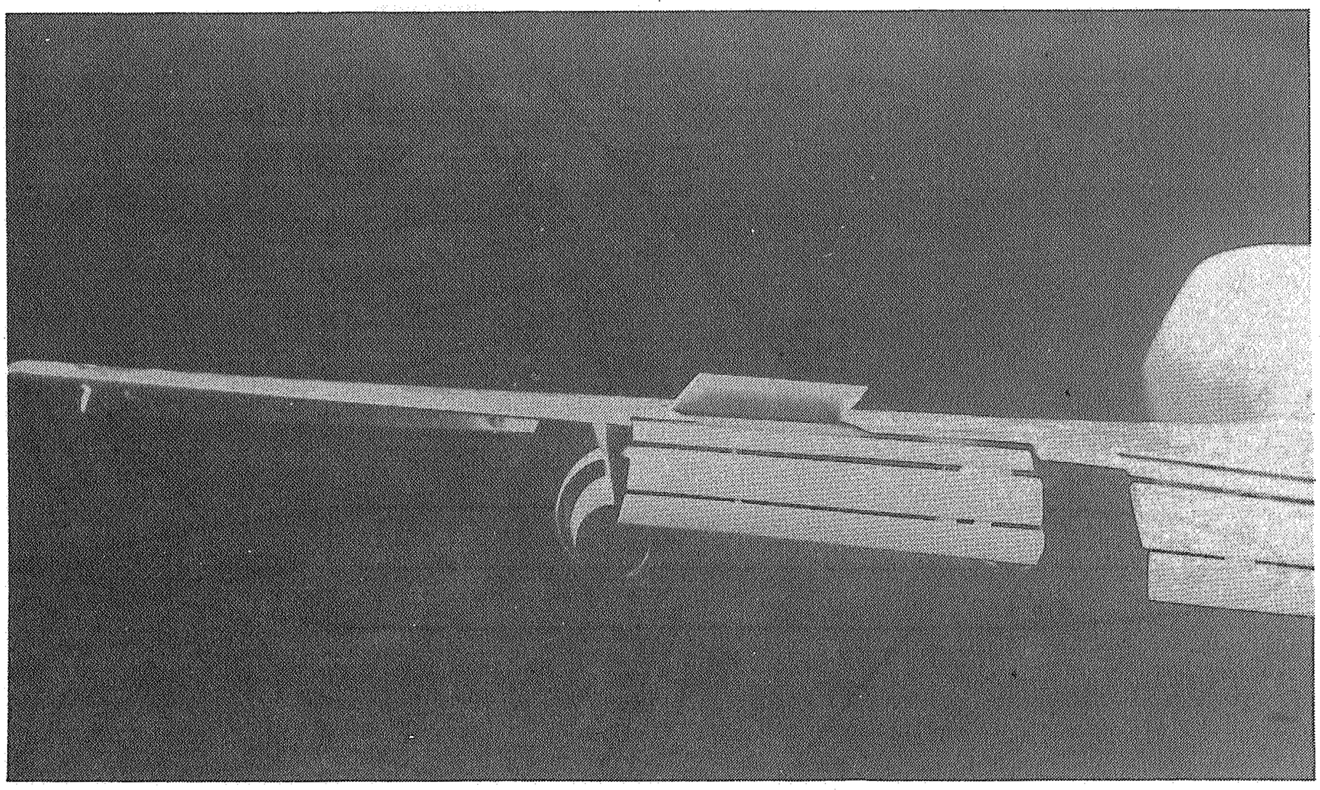


Figure 17.--Flight spoilers 1 and 2 on transport model.

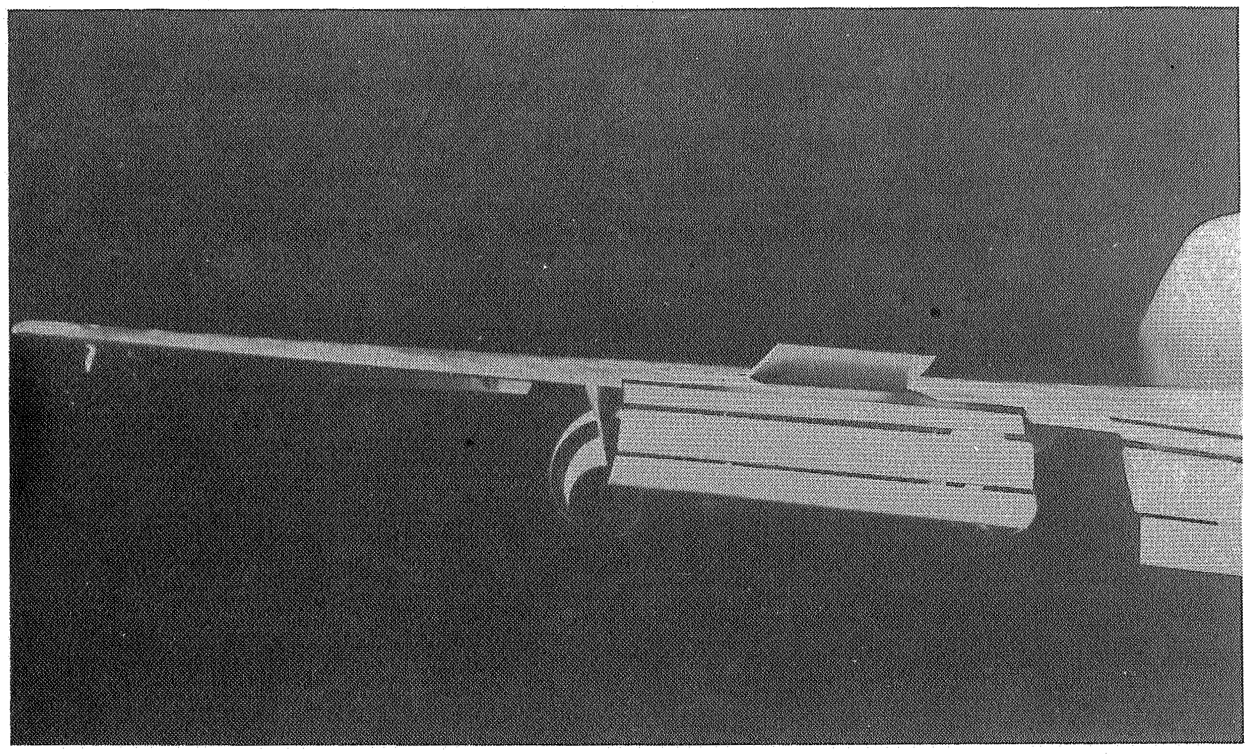


Figure 18.--Flight spoilers 2 and 3 on transport model.

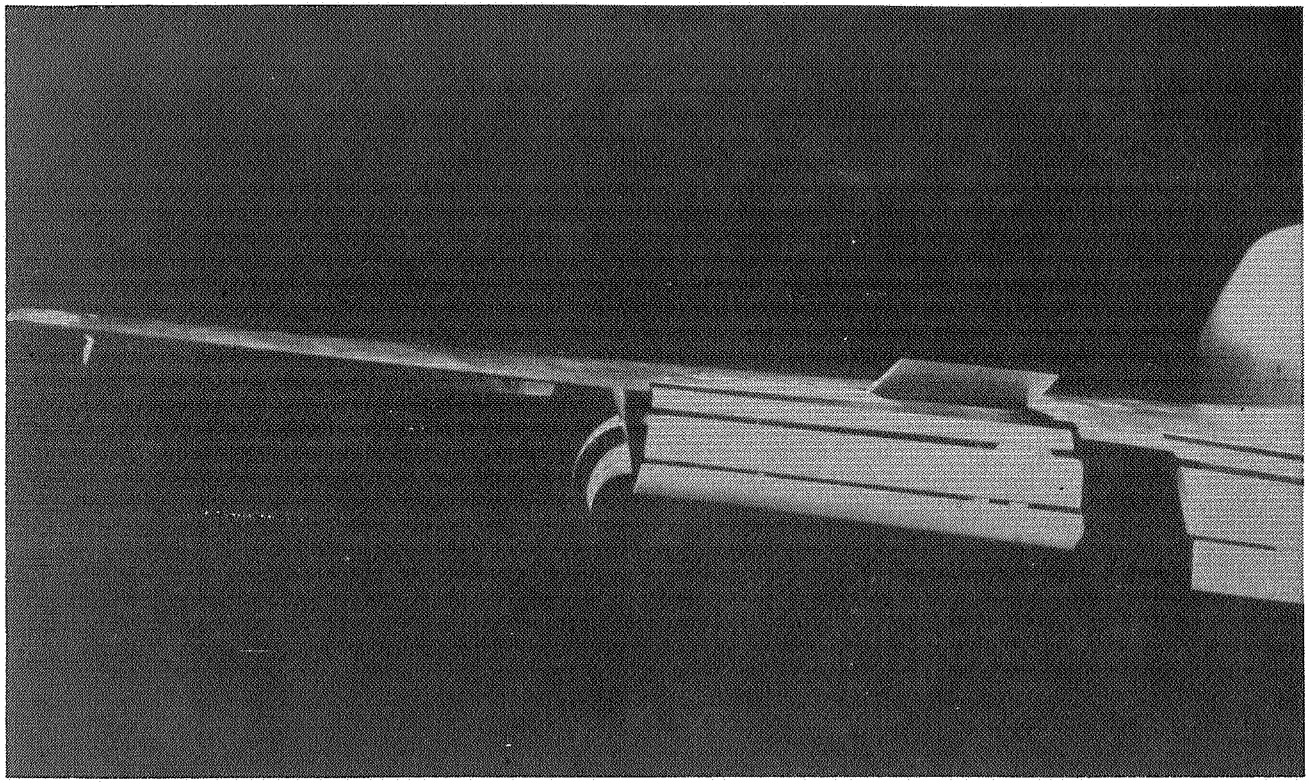


Figure 19.--Flight spoilers 3 and 4 on transport model.

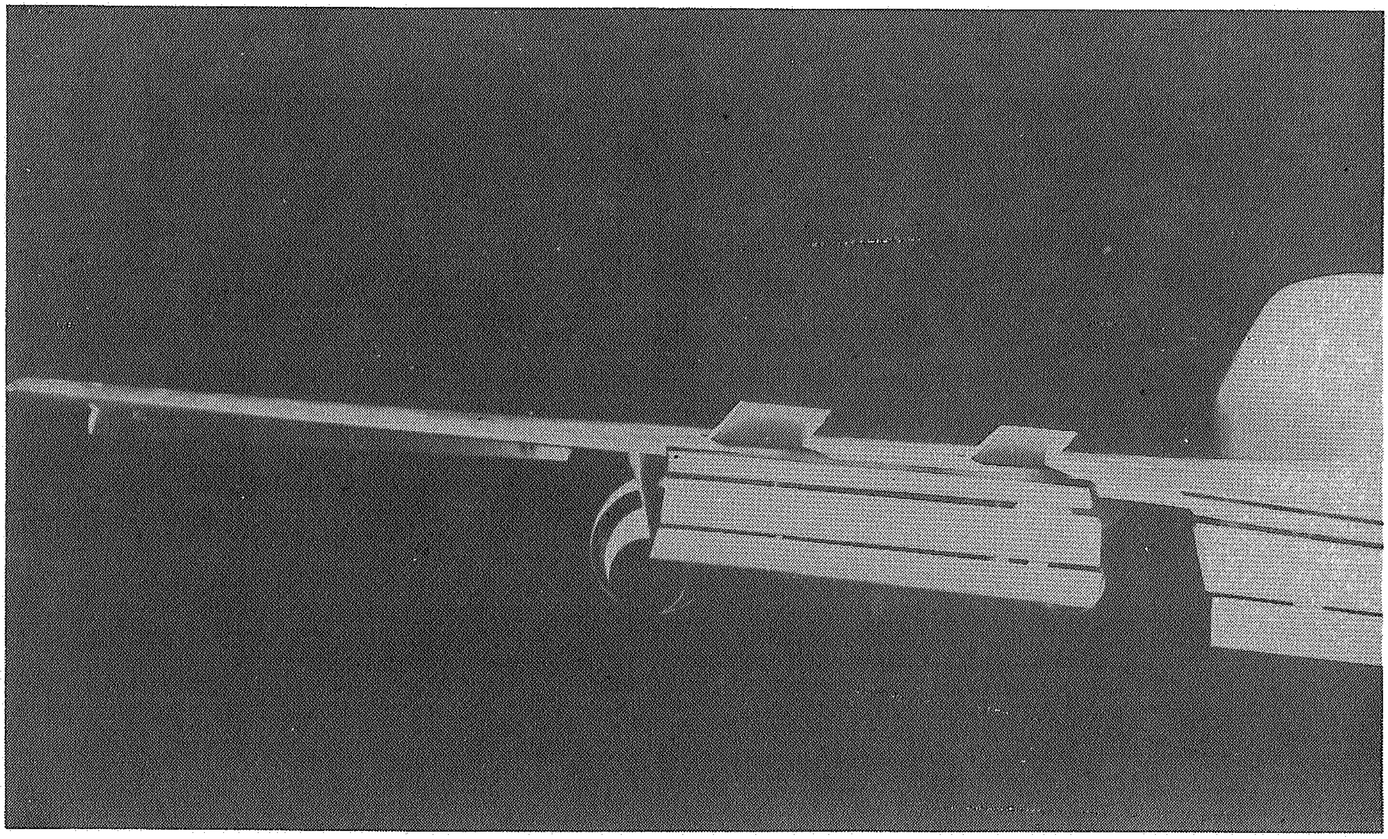


Figure 20.--Flight spoilers 1 and 4 on transport model.

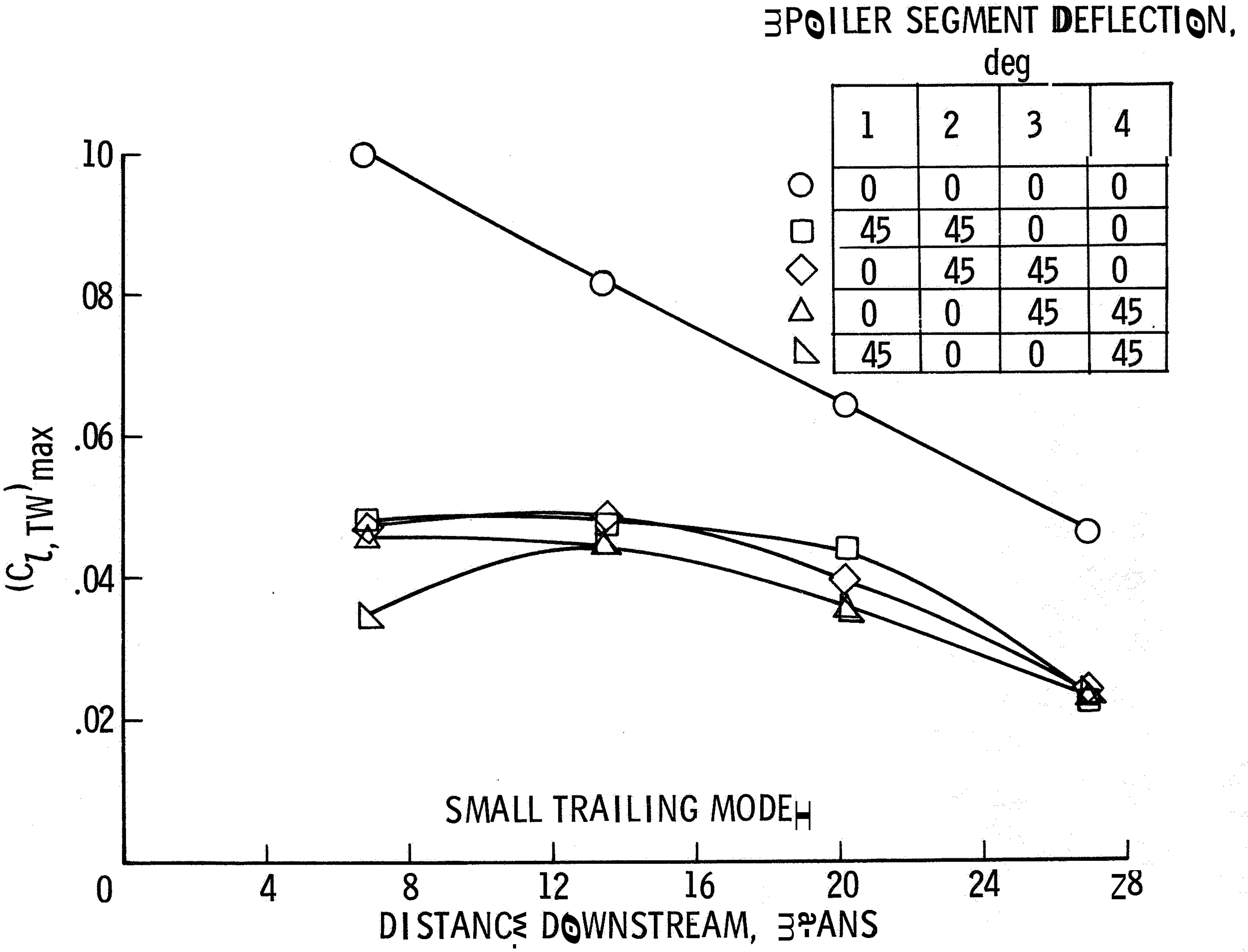


Figure 21.--Variation of trailing wing, rolling-moment coefficient with distance downstream from transport model. Flight spoilers; $C_{L,trim}$ = 1.2

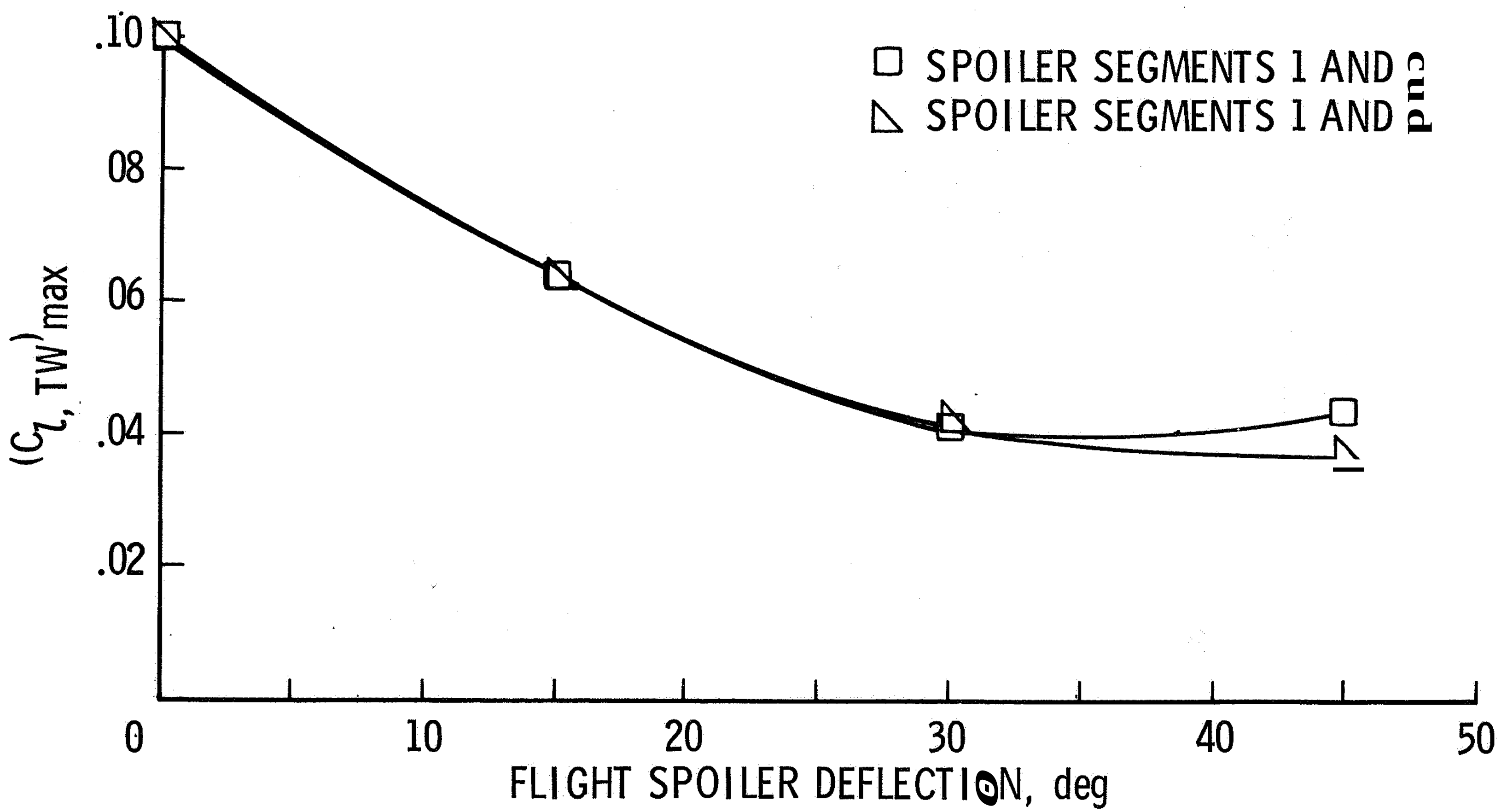
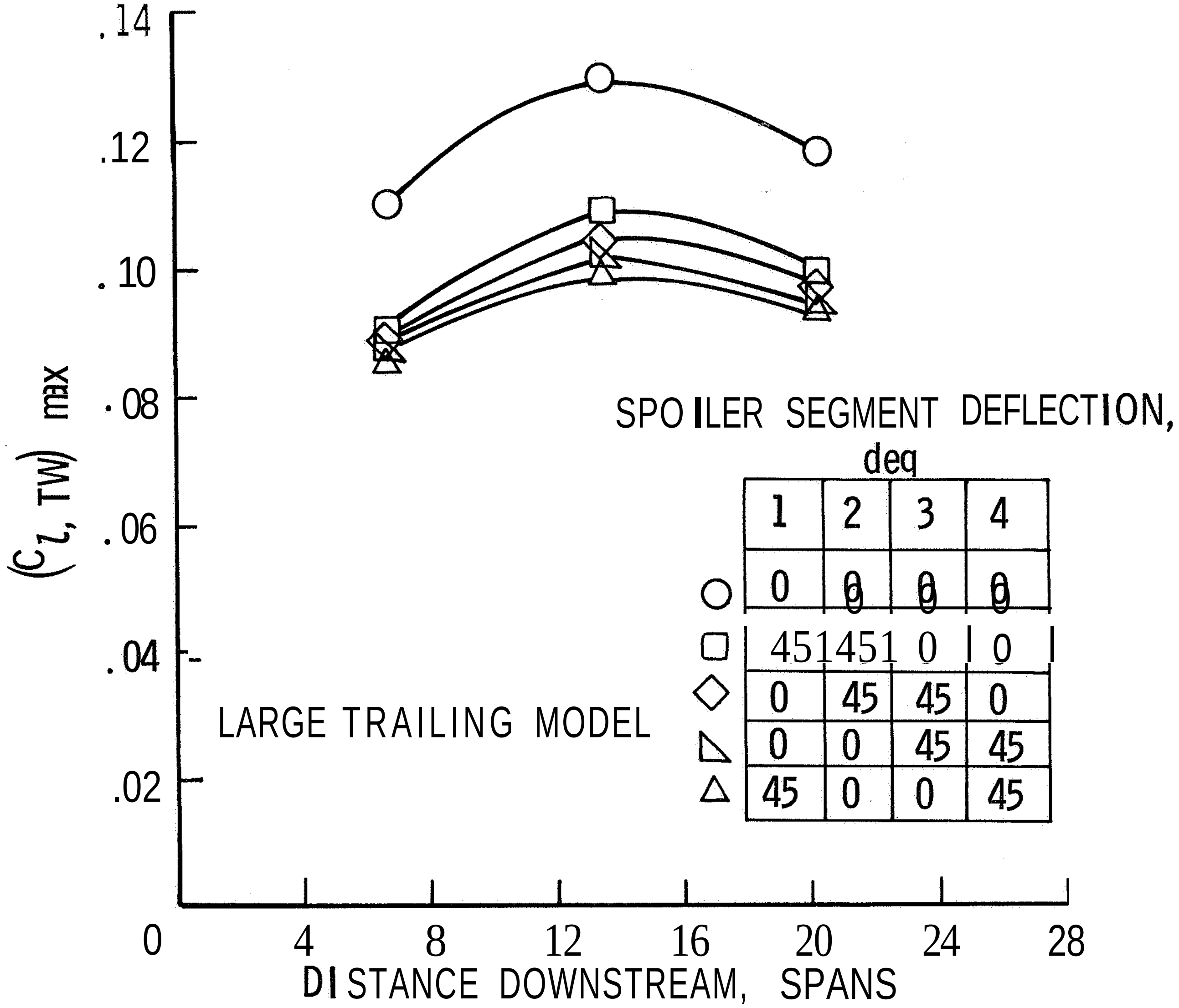


Figure 22.--Variation of trailing wing, rolling-moment coefficient with spoiler deflection. Flight spoilers; $C_{L,trim}$ = 1.2; 6.7 spans downstream.



	1	2	3	4
○	0	0	0	0
□	45	45	0	0
◇	0	45	45	0
◺	0	0	45	45
△	45	0	0	45

Figure 23.--Variation of trailing wing, rolling-moment coefficient with distance downstream from transport model. $C_{L,trim}$ = 1.2,

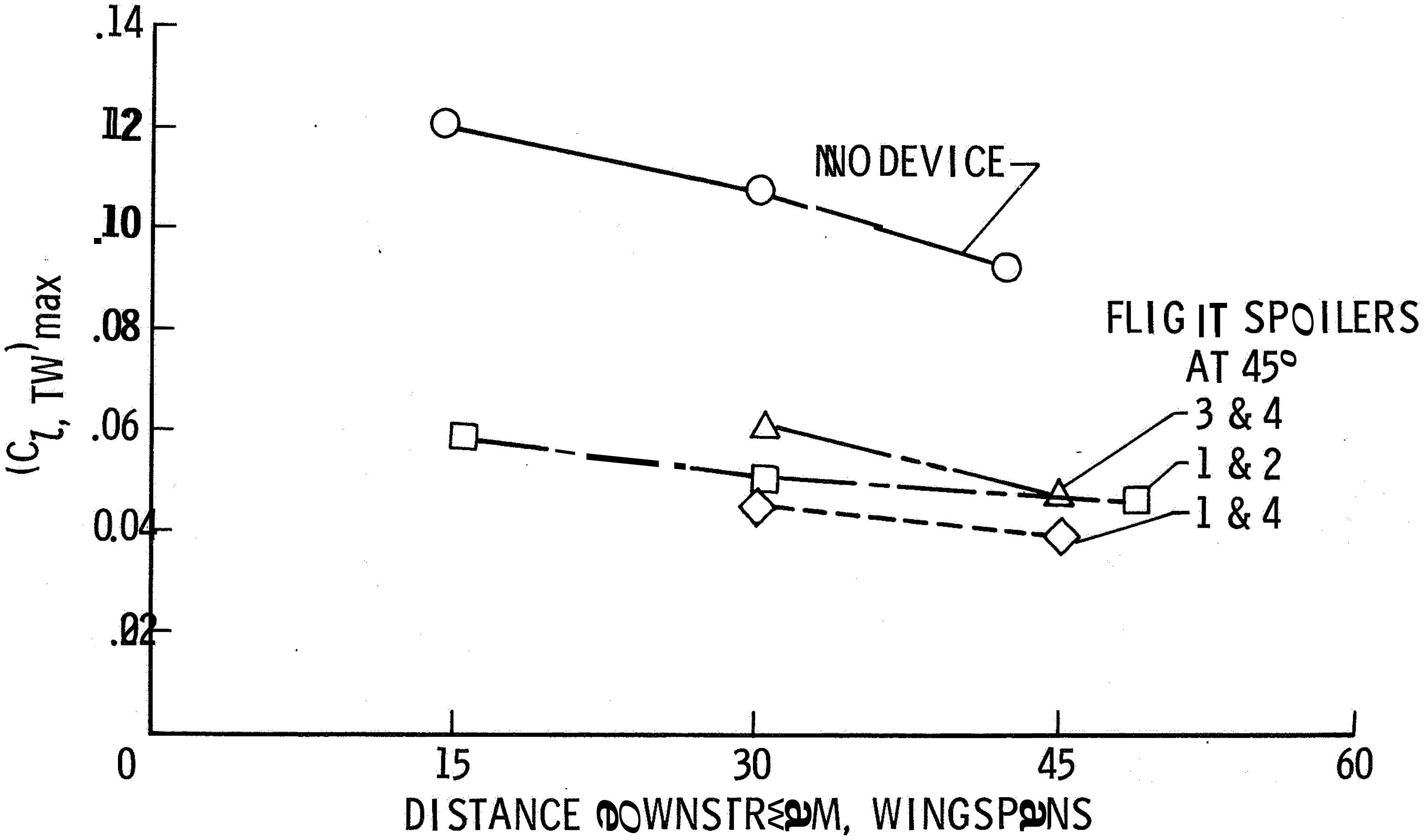


Figure 24.--Transport model flight spoiler, water towing tank, small trailing model. $C_L = 1.2$.

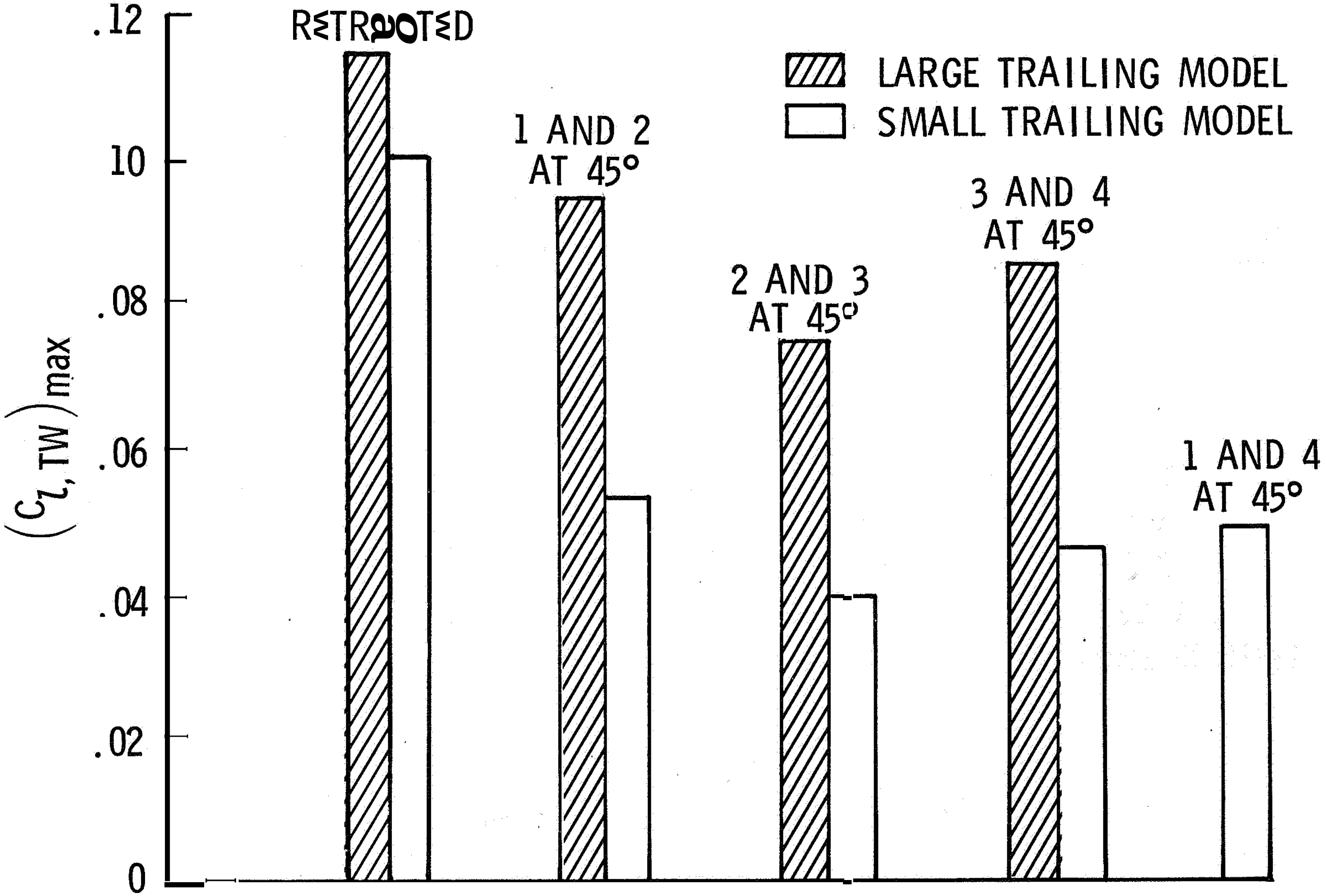


Figure 25.--Transport model flight spoilers, Langley Vortex Research Facility. C_L = 1.45; 27 spans downstream.