5828?9
P. 20

THRUST-AUGMENTED VORTEX ATTENUATION

James C. Patterson, Jr., and Frank L. Jordan, Jr.
NASA Langley Research Center

SUMMARY

An experimental investigation has been conducted in the Langley Vortex Research Facility to determine the vortex attenuating effect of engine thrust. Tests were made using a 0.03-scale model of the Boeing 747 transport aircraft as a vortex-generating model. A Learjet-class probe model was used to measure the vortex-induced rolling moment at a scale separation distance of 1.63 km (0.88 n. mi.). These tests were conducted at a lift coefficient of 1.4 at a model velocity of 30.48 m/s.

The data presented in this paper indicate that engine thrust is effective as a vortex attenuating device when the engines are operated at high thrust levels and are positioned to direct the high-energy engine wake into the core of the vortex. The greatest thrust vortex-attenuation is obtained by operating the inboard engine thrust reversers at one-quarter thrust and the outboard engines at maximum forward thrust.

INTRODUCTION

The lift-induced wingtip vortex associated with the large wide-body jet transport aircraft of today has become a major problem in the terminal area resulting from the large upset rolling moment induced on smaller following aircraft. The persistent nature of this type of flow has also resulted in an unseen hazard during cruise flight long after the generating aircraft has passed. The wingtip vortex, the strength of which is a function of lift for a particular aspect ratio and wing planform, has been in existence since the beginning of flight, becoming an ever-increasing problem as the weight of each succeeding generation of aircraft has increased. A NASA-wide research effort is now underway to reduce or possibly eliminate this lift-induced vortex by some means that could be retrofitted to existing aircraft to cope with the vortex persistence problem.

The high-energy wake produced by the large jet engines required for the wide body transports of today has been proposed as a means of attenuating the lift-induced vortex. Results of tests conducted to determine the vortex attenuation due to engine thrust level, thrust position, and the effect of reverse thrust are presented here. Visual data indicating the effect of thrust on the circulatory field surrounding the vortex as well as the effect on the vortex are included with the vortex-induced rolling-moment measurements made at 1.63-km (0.88-n.-mi.) scale distance behind the vortex generating model.

APPARATUS AND PROCEDURE

Facility Description

An overall view of the internal modification made to the towing tank in the transition from the model towing basin to a Langley Vortex Research Facility is shown in figure 1. The carriage is shown mounted on the 548.64-m overhead track with a transporttype vortex-generating aircraft model blade mounted beneath this carriage. A vortex probe model is located at 48.77 m, a scale distance of 1.63 km(0.88 n. mi.) downstream of the vortex-generating model. By using the flow visualization system discussed in reference 1, the position of this model relative to the vortex core is determined visually during each test, while the induced rolling moment is recorded in the facility test section.

The test section, constructed to isolate the wake of the carriage and trailers from the model wake, is 91.44 m long, 5.49 m wide, and 4.27 m high with a 5.10-cm opening along the center of the ceiling to allow the model blade mounts to pass. The exterior of the building shown at the entrance of the test section encloses the entire length of the track.

Test Models

The vortex-generating model in figure 2 is a 0.03-scale model of the B-747 jet transport aircraft and is shown blade mounted on an internal six-component strain-gage balance. High-pressure air is piped from a bottle field onboard the vehicle down the rear portion of the model blade mount to each engine nacelle for thrust simulation. The thrust of each engine is individually controlled to allow a difference in thrust level between the inboard and outboard engines. The model is equipped with both leading- and trailing-edge flaps to simulate the landing configuration.

The probe models used to measure the roll induced by the vortex of the E-747 model are shown in figure 3. The smaller of the two models is in the Learjet class; the other is similar in scale size to the DC-9 transport. The models include two swept and tapered wings plus two unswept untapered research wings having the same span and aspect ratio as the swept wings. The vertical and lateral position of the following model may be varied to fix this model in the vortex generated by the E-747 model. This position of the roll model is recorded by a television camera to allow an instant replay of each test to determine the degree of vortex core penetration. The internal strain-gage balance used with these models is also shown in this figure. All models were constructed of fiber glass and aluminum.

PRESENTATION OF RESULTS

A sequence of photographs of the vortex flow created by a E-747 model in the Langley Vortex Research Facility is shown in figure 4. These photographs were taken at approximately 0.5-s intervals while the model traversed a distance of approximately nine wing spans between each photograph.

The moment the vortex-generating model penetrates the smoke screen, the vortex system produced by this model becomes visible and may be observed for some time after the model has passed. The wing-tip vortex and the vortex produced by the outer edge of the outboard flap are shown for each wing panel in the first photograph. These two vortexes produced by each wing panel orbit about a common axis forming a single vortex within four wing spans behind the model. This results in the classical vortex sheet emanating from a lifting wing rolling into a single vortex in the vicinity of each wingtip, shown in the sequential photographs. These two vortexes move downward under the influence of the wing downwash, and the vortex cores become visible with time as a portion of the smoke material is induced upstream along the periphery of the vortex core. This movement of the smoke along the vortex core possibly results from the lower pressure associated with the more recently formed wake upstream of the smoke screen. Beyond the radius of the rotational flow of the vortex core, the irrotational potential flow region can be seen. In the effort to reduce or eliminate the vortex hazard through a reduction in vortex flow, it should be kept in mind that the circulation flow shown can only be eliminated by canceling the total lift to the aircraft. By converting the angular momentum of the persistent vortex flow into linear momentum or turbulent flow, the vortex-circulatory wake system may possibly be caused to dissipate more rapidly.

Thrust Effect

The rolling moment induced by the vortex is obtained with the probe model as it penetrates the vortex shown in the last photograph of figure 4 taken 1.6 s after the vortex-generating model had passed the test position. The lift-induced vortex is responsible for 40 to 50 percent of the cruise drag in the form of induced drag and approximately 70 percent of the drag during landing. This large amount of energy associated with the vortex will require a large energy input to cause the vortex to break down. It has been shown in references 2 and 3 that by forcing a mass of air forward into the vortex the axial flow in the vortex core is disrupted such that the vortex becomes unstable and breaks down as shown in reference 4. The jet exhaust wake of the large engines employed on today's transport is a source of high energy that when properly directed into the vortex core may trigger this same dissipating effect on the vortex.

Tests have been conducted with the model engine simulators on the B-747 model operated at a static gross sea level thrust comparable to the maximum thrust obtainable by the full-scale transport aircraft. The landing gear is extended for all tests as a result of the unexpected increase in vortex strength discovered as a result of extending the landing gear. (See ref. 5.) The visual data of the effects of engine thrust on the vortex formation are presented in figure 5. The wingtip and flap vortexes do not appear as distinct as for the zero thrust case when the high-energy jet engine exhaust from the inboard and outboard engines is introduced on either side of the final vortex rollup position. This final position was found to be approximately 55 percent of the wing semispan during the investigation of the spline vortex attenuating device (ref. 2). The attenuating effect of the thrust should be greater than that of the spline device because of the continued injection of an air mass from the engines into the vortex formed at a particular position along the flightpath, The amount of engine exhaust that reaches the vortex, of course, decreases as the separation distance between the aircraft and this position increases. The downwash produced by the wing is apparent in this figure as well as the circulatory field in the vicinity of each wingtip.

The effect of thrust on the rolling-moment coefficient induced on the Learjet class aircraft probe model by the vortex of the B-747 transport model with full landing flaps is presented in figure 6. The jet engine wake has an attenuating effect on the vortex that reduces the measured rolling moment by approximately 20 percent of the zero thrust case at the separation of 1.63 km (0.88 n. mi.).

The results of flight tests conducted by the Flight Research Center using the B-747 jet transport aircraft indicate the similar thrust attenuating effect on the induced vortex (ref. 6). At a separation distance of approximately 9 km (5 n. mi.), the vortex-induced rolling moment measured by the small jet aircraft (Learjet class) was increased on an average by approximately 40 percent when the thrust was reduced from that required for level flight with full flaps deployed, to an idle thrust level. More recent flight tests at a separation distance of approximately 6.5 km (3.5 n. mi.) also indicate this same reduction in vortex strength resulting from the dissipating effect of the engine thrust on the vortex.

Engine Location

Neither of the engines on one wing panel of this model configuration is directly aligned with the vortex spanwise-rollup position. The outboard engine is located at the 70-percent semispan station, and the inboard engine is at 40 percent. As stated, the position of final vortex rollup is approximately 55 percent of the semispan for this model; therefore, it should be expected that the effect of thrust shown here is not the maximum.

In an attempt to increase the vortex attenuation resulting from engine thrust, the outboard engine on the vortex B-747 model was moved inward along the wing leading edge to the 55-percent semispan station. The induced rolling-moment model results obtained with the outboard engine in this new position, with and without thrust, are presented in figure 7. The vortex induced roll value for the thrust-off case is slightly higher than with the engine at the 70-percent semispan position, possibly resulting from the reduced underwing fencing effect offered by the engine-pylon combination located further out along the wing span. Interruption of the spanwise flow under the wing would tend to reduce the strength of the vortex, as an associated change in span load would indicate. Applying maximum thrust with the outboard engines at the 55-percent semispan position results in an additional 50-percent reduction in vortex-induced rolling moment. This result demonstrates not only the vortex attenuating effect of engine thrust, but also the importance of properly directing this energy.

Thrust Reversers

Because the high engine thrust levels required to obtain an appreciable reduction in vortex strength may not be applicable to the landing case, it has been suggested that the jet engine thrust reversers might be employed as a vortex attenuating device. The reversers on the B-747 operate by directing the fan flow and primary flow of the fan-jet engines approximately 26° forward of the vertical plane, resulting in approximately 42 percent of the total engine thrust reversed.

Model tests were conducted using an annular structure at the model engine fan exit to turn the fan flow 120" simulating the full-scale engine reverser. The vortex-induced rolling moment results obtained with the two outboard or two inboard engine thrust reversers deployed, operating at 25-percent maximum forward thrust, and with the nonreversed engines operating at full thrust are presented in figure 8. The inboard engine reversers are approximately three times as effective as the outboard reversers, resulting in a 60-percent reduction in the measured vortex rolling moment. The visual data for the inboard reverser configuration are presented in figure 9. Comparison of these data with those of figure 4, basic configuration without thrust, indicates that the vortex core has been eliminated while the accompanying circulation has been greatly reduced. Full-scale flight tests of reverser effectiveness have been conducted recently using the B-747 airplane without landing flaps deployed. A significant reduction in the actual roll upset of the probe aircraft was achieved by operating the outboard engine reversers at idle thrust while the inboard engines developed maximum thrust.

Multivortex System

Tests were conducted to determine the effect of a variation in span lift loading on vortex dissipation. The span load was altered by retracting the outboard flaps, resulting in the vortex system shown by the visual data presented in figure 10. These data indicate that for the zero-thrust case there is a distinct wingtip and flap vortex system. The vortexes that form on the inner edge of each inboard flap tend to dissipate each other as a result of their opposite senses of rotation and proximity aided by the end-plate effect of the nearby fuselage. Vortexes that formed at the flap outer edges orbited with the wingtip vortexes until the flap vortex flow broke down at approximately 0.78 km (0.43 n. mi.) downstream from the model. The wingtip vortex persisted long after that, as indicated by the well-defined vortex in the last photograph of the figure at a separation distance of 1.63 km (0.88 n. mi.).

The effect of thrust on the multivortex system resulting from deploying only the inboard flaps is presented visually in figure 11. The core of each vortex is visually dissipated and circulation has been reduced as shown previously as a result of the engine wake.

The measured rolling-moment coefficient increased from a value of approximately 0.03 to 0.04 when the full engine thrust was applied to the inboard flap configurations. This result was unexpected and had not been experienced in previous engine thrust tests. In reviewing the videotaped visual data, it was apparent that in the zero-thrust case, the wingtip vortex had moved into such a position relative to the probe model at the scale distance of 1.63 km (0.88 n. mi.) that its influence tended to reduce the rolling moment induced by penetration of the flap vortex. The dissipating effect of thrust on the wingtip vortex reduced the favorable effect of this vortex on the probe model, resulting in the larger flap vortex-induced roll.

There was some indication during the full-scale flight tests of this mutual effect of the vortexes on the probe aircraft in multivortex systems. These effects have been associated with a change in separation distance between the generating and probe aircraft that alters the relative position of each vortex to the probe aircraft.

CONCLUDING REMARKS

An experimental investigation to determine the dissipating effect of engine thrust on the lift-induced vortex of a model B-747 transport aircraft indicated that--

(1) The strength of the lift-induced vortex of the B-747 may be attenuated by the thrust of the large fan-jet engines employed by this transport.

(2) The thrust-augmented vortex attenuation may be maximized by proper engine location relative to the vortex.

(3) Deploying the thrust reverser on the inboard engines at low thrust levels is a very effective method of achieving a large degree of vortex attenuation.

(4) The mutual effect of the vortexes in a multivortex system may enhance as well as attenuate the rolling moment induced on a following aircraft as a result of the relative position of each vortex to the probe aircraft,

REFERENCES

1. Patterson, J. C., Jr.; and Jordan, Frank L., Jr.: A Static-Air Flow Visualization Method to Obtain a Time History of the Lift-Induced Vortex and Circulation. NASA TM X-72769, 1975.

2. Patterson, J. C., Jr.: Vortex Attenuation Obtained in the Langley Vortex Research Facility. J. Aircraft, vol. 12, no. 9, Sept. 1975, pp. 745-749.

3. Hastings, E. C., Jr.; Patterson, J. C., Jr.; Shanks, R. E.; Champine, R. A.; Copeland, W. L.; and Young, D. C.: Development and Flight Tests of Vortex-Attenuating Splines. NASA TN D-8083, 1975.

4. Hall, M. G.: Vortex Breakdown. Annual Review of Fluid Mechanics. Vol. 4, M. Van Dyke, W. G. Vincenti, and J. V. Wehausen, eds., Annual Reviews, Inc., 1972, pp. 195-218.

5. Patterson, J. C., Jr.; and Jordan, F. L., Jr.: An Investigation of the Increase in Vortex Induced Rolling Moment Associated With Landing Gear Wake. NASA TM X-72786, 1975.

6, Smith, H. J,: A Flight Test Investigation of the Rolling Moments Induced on a T-37B Airplane in the Wake of a B-747 Airplane. NASA TM X-56031, 1975,

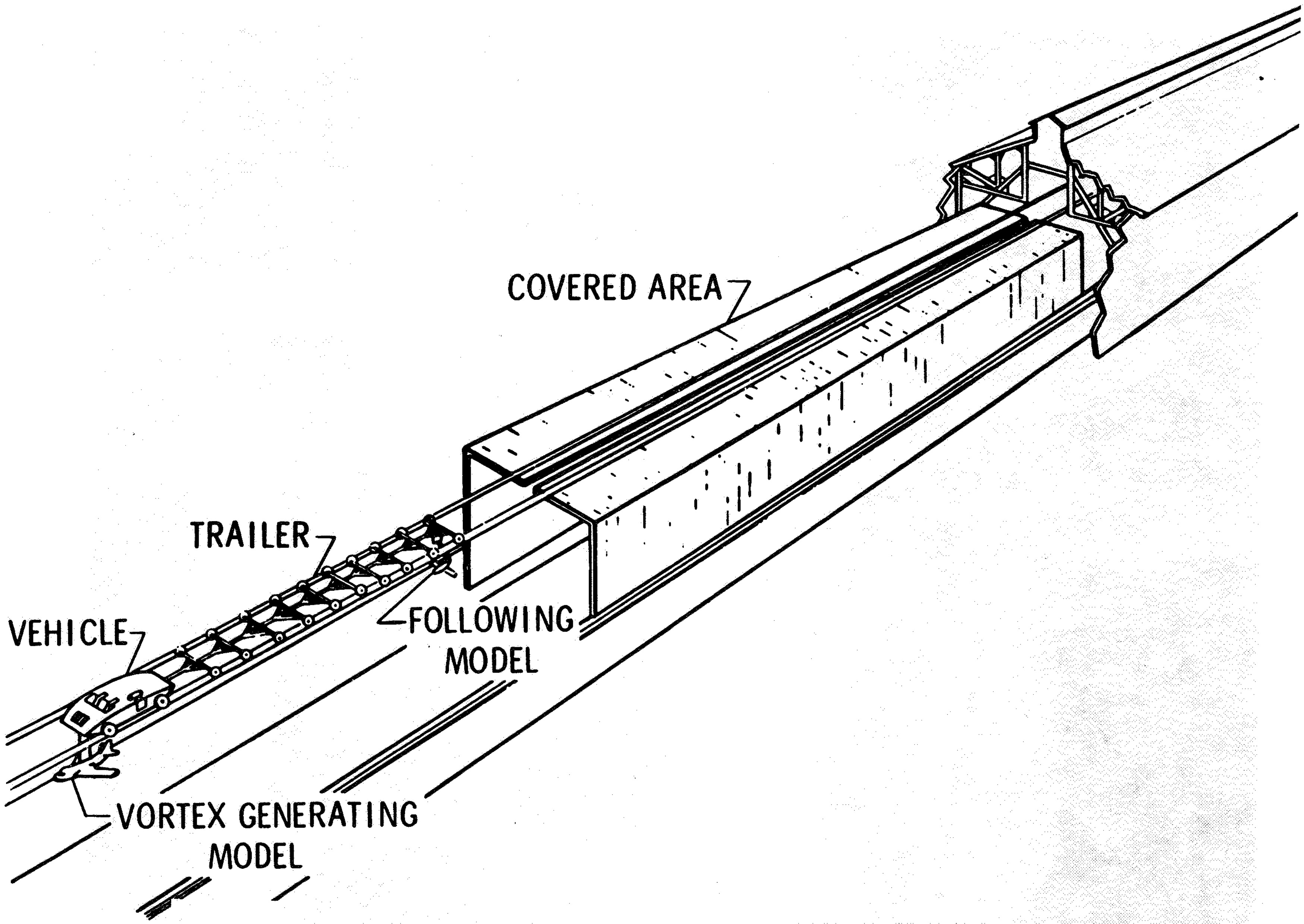

Figure 1.--Arrangement of the Langley Vortex Research Facility.

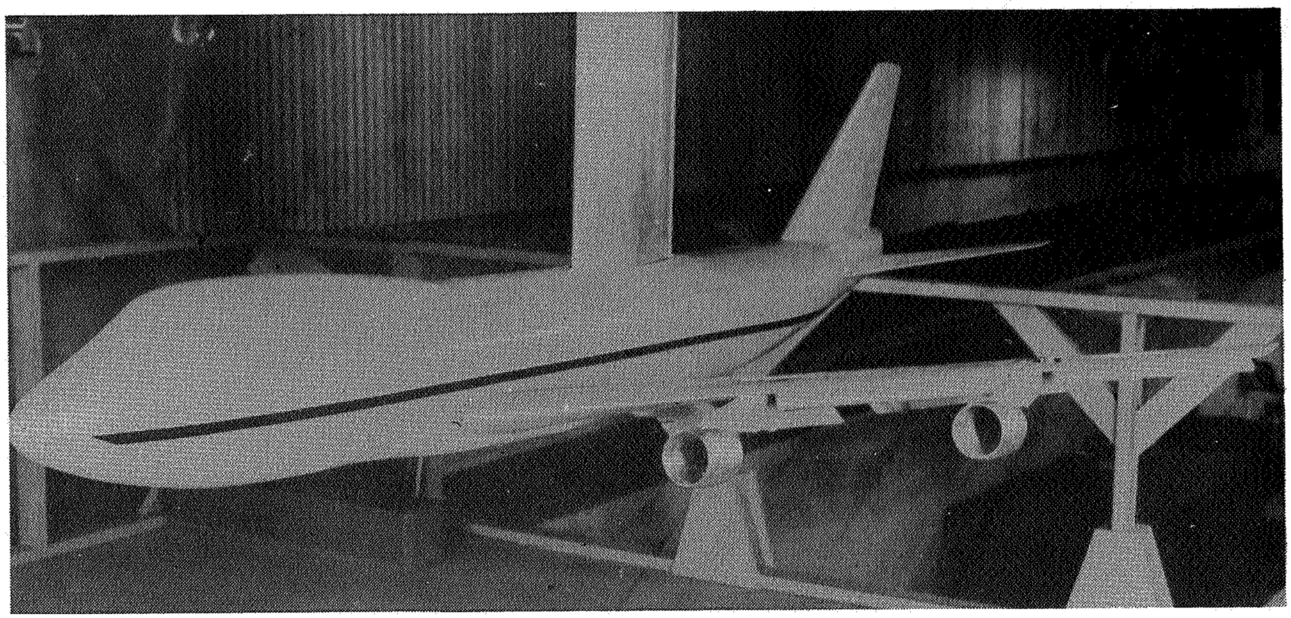

Figure 2.--Photograph of the 0.03-scale-model wide-body jet transport aircraft used as vortex generating model.

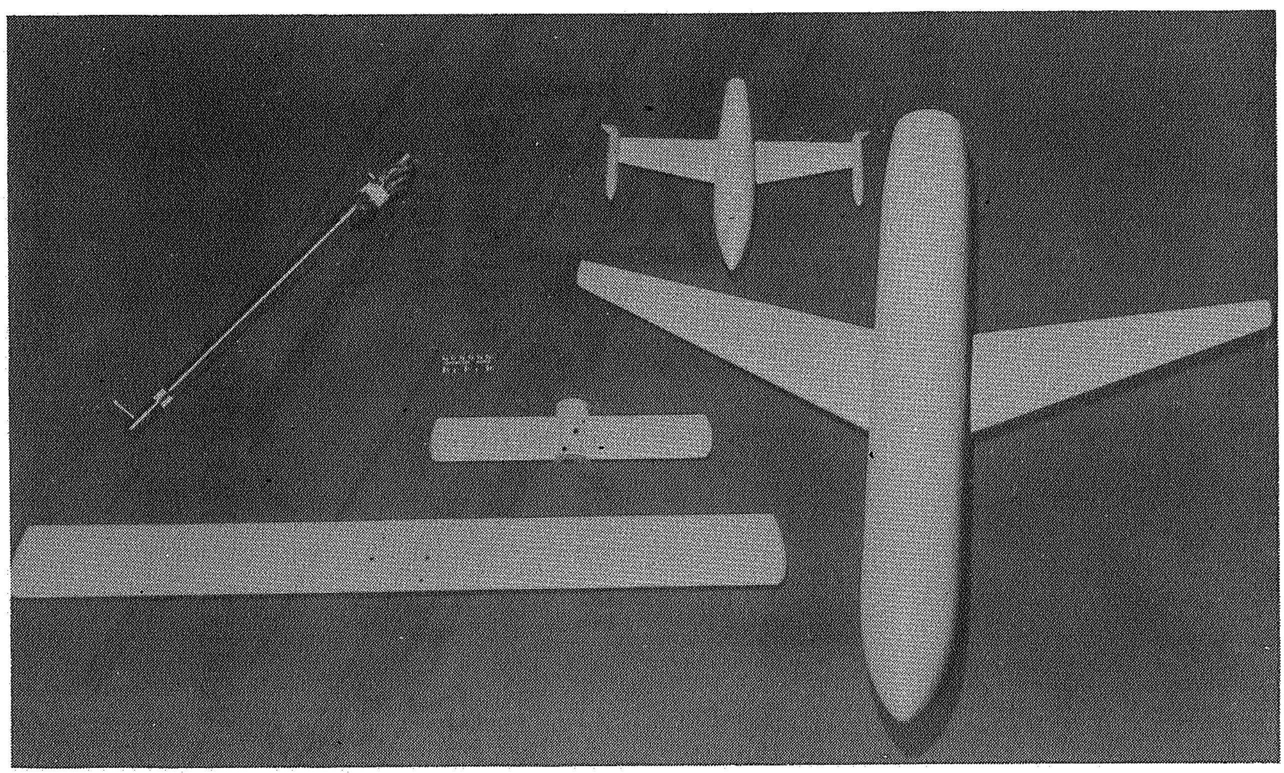

Figure 3.--Photograph of the 0.03-scale-model DC-9 and Learjet-class aircraft used as vortex probe models.

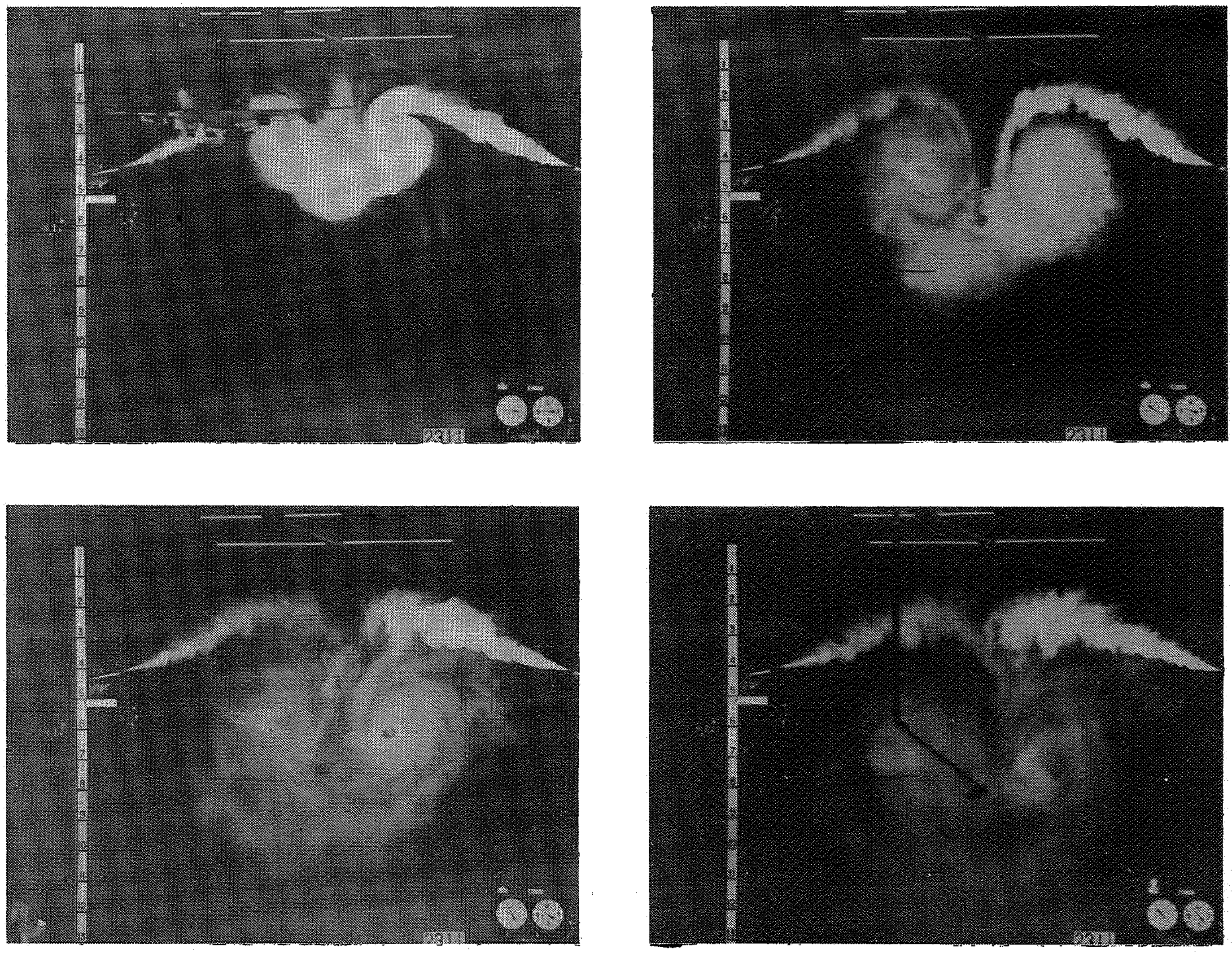

Figure 4.--Lift-induced vortex system created by 0.03-scale-model of wide-body jet transport aircraft (flaps deflected 30°). Photographic sequence rate corresponds to a separation distance of 0.54 km. Following model is centered in vortex in lower right photograph. Lift coefficient = 1.40; velocity = 30.48 m/s.

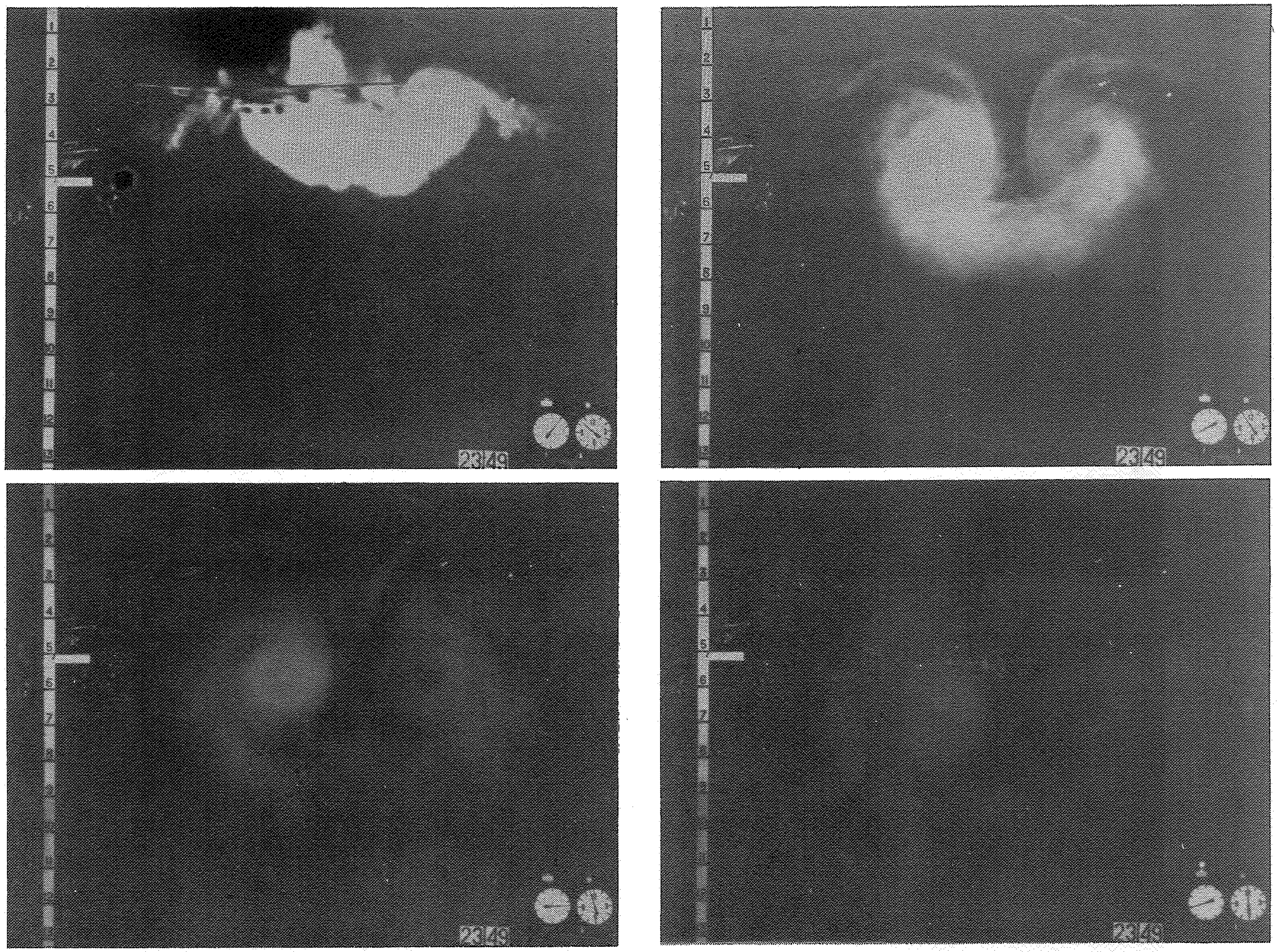

Figure 5.--Effect on maximum engine thrust on vortex system of transport aircraft model in figure 4 (flaps deflected 30°).

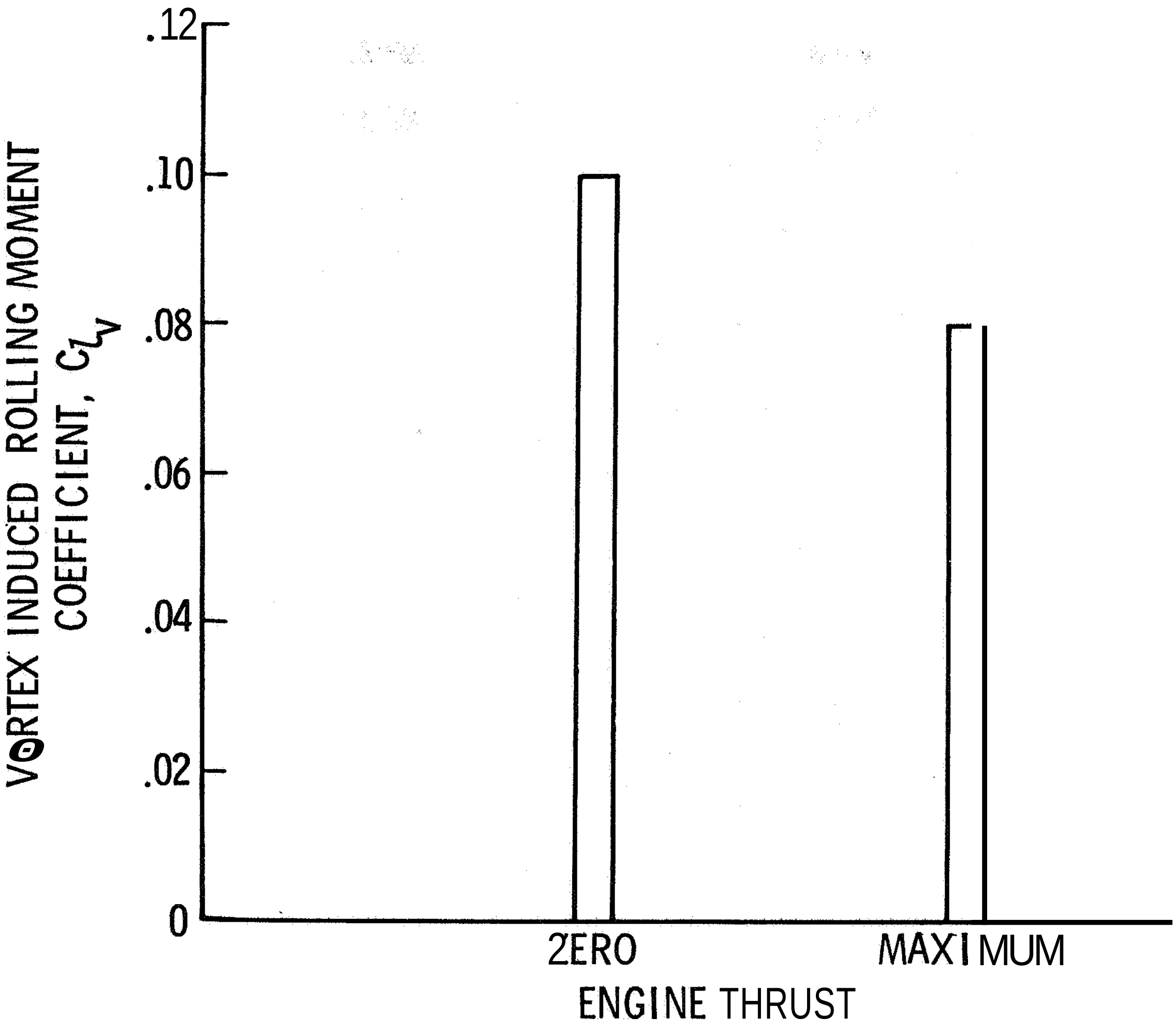

Figure 6.--Effect of engine thrust on vortex-induced rolling moment coefficient with Learjet-class chase model. Lift coefficient = 1.40; separation distance = 1.63 km (0.88 n. mi.).

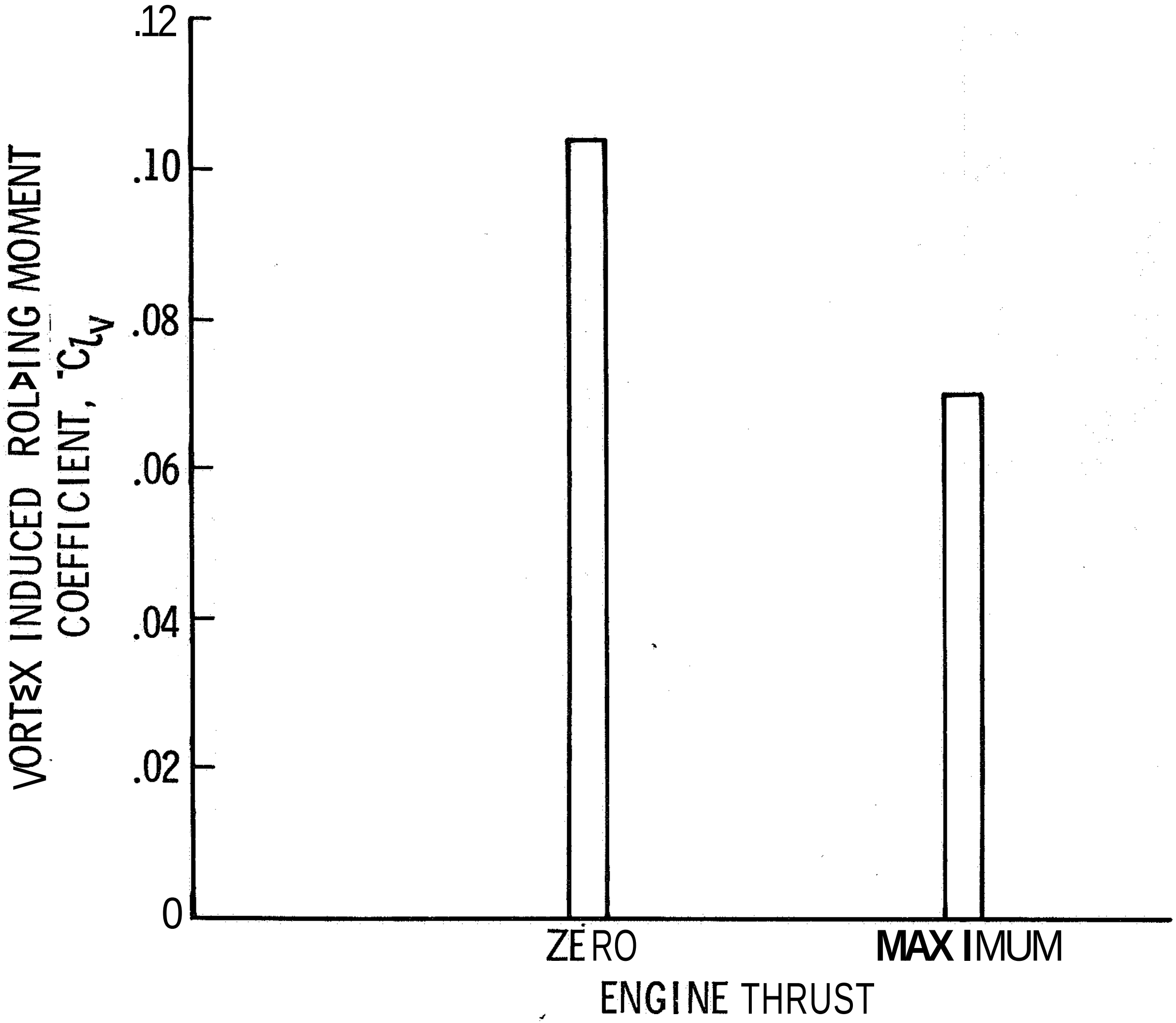

Figure 7.--Effect of engine thrust on vortex-induced rolling moment coefficient with outboard engines located at 55 percent of wing semispan and Learjet-class chase model. Lift coefficient = 1.40; separation distance = 1.63 km (0.88 n. mi.).

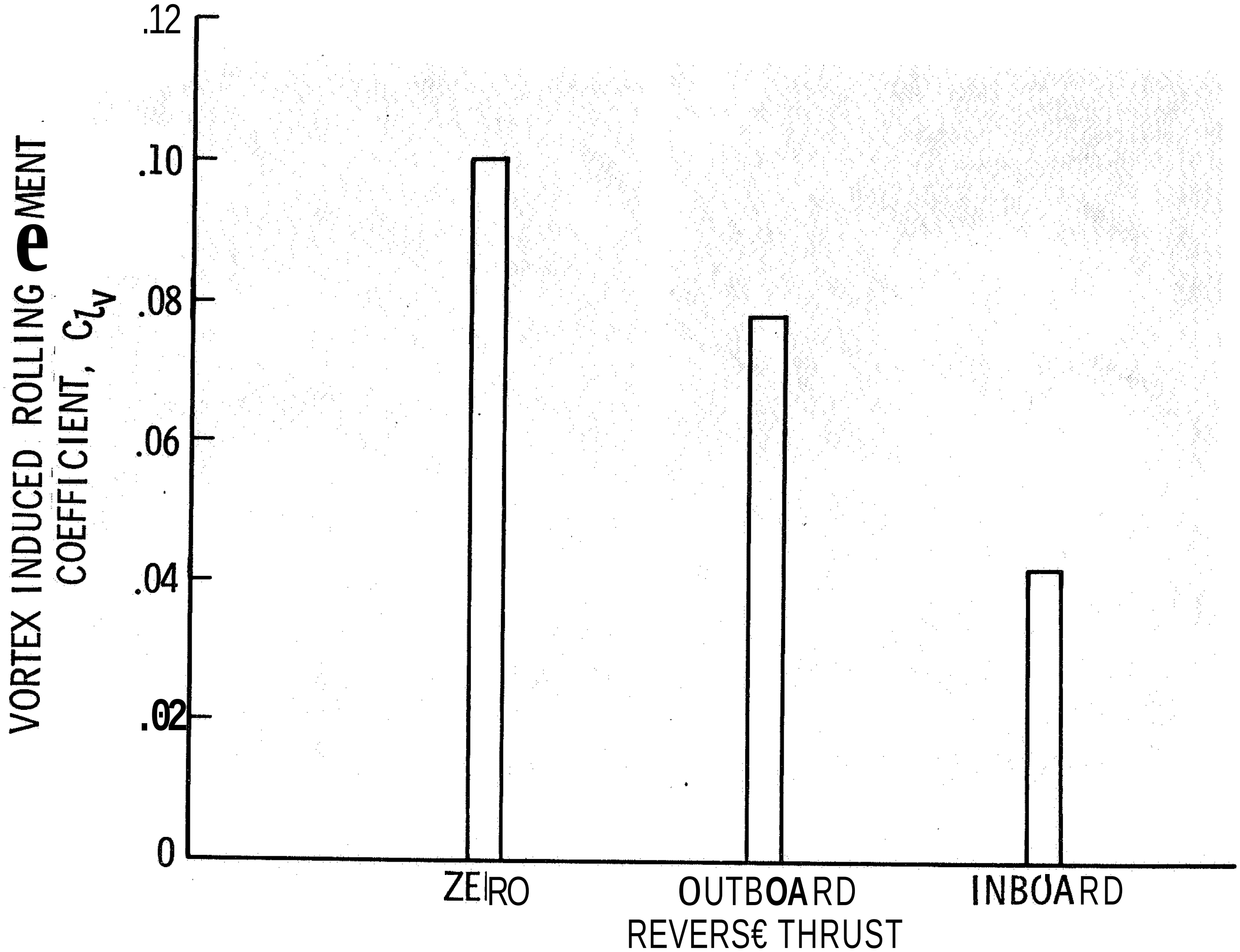

Figure 8.--Effect of engine reverse thrust on vortex-induced rolling-moment coefficient with Learjet-class chase model. Lift coefficient = 1.40; reverse thrust, 1/4 maximum; forward thrust, maximum; separation distance = 1.63 km (0.88 n. mi.).

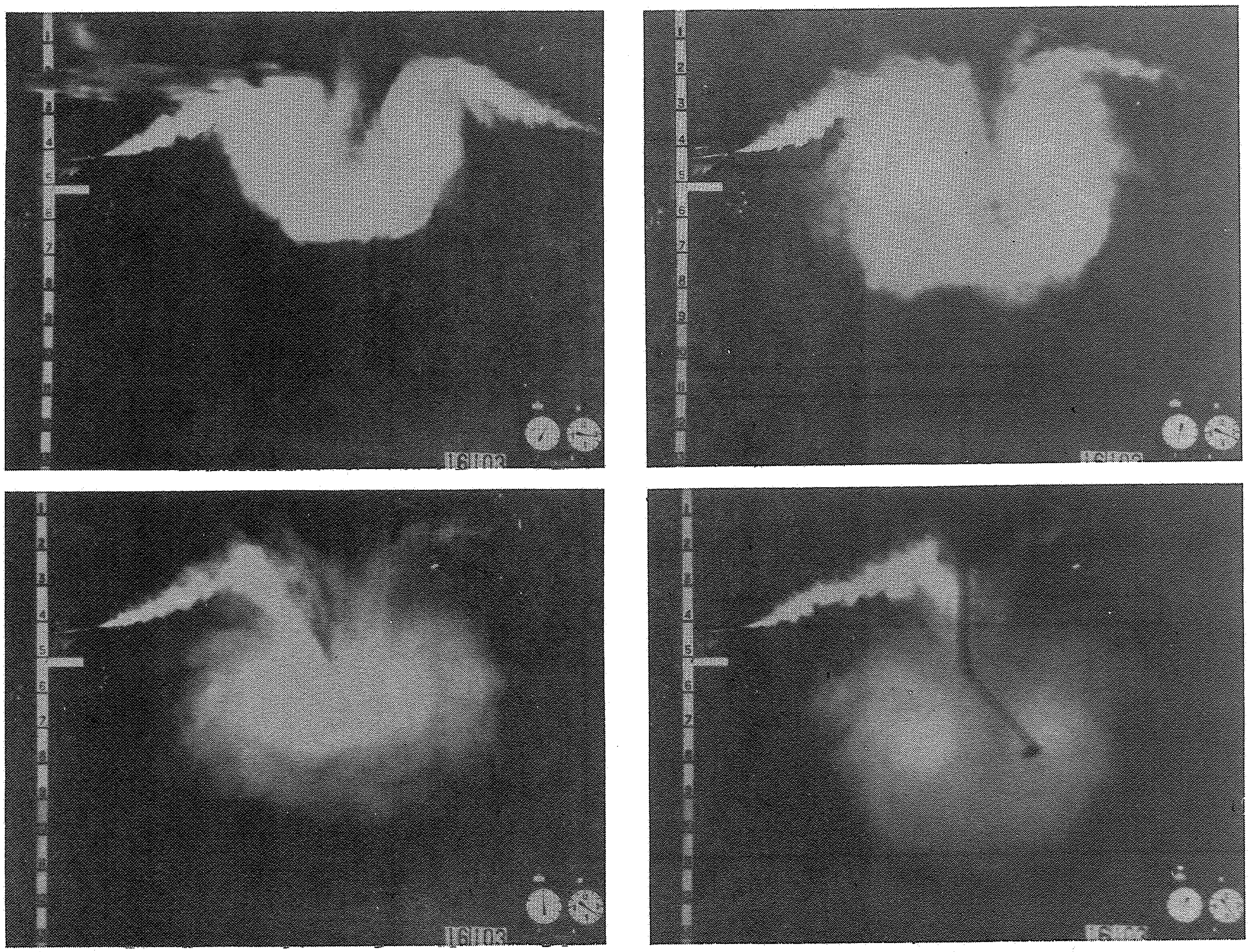

Figure 9 --Effect of inboard engine reverse thrust on vortex system of wide-body jet transport aircraft model in figure 4 (flaps deflected 30°)

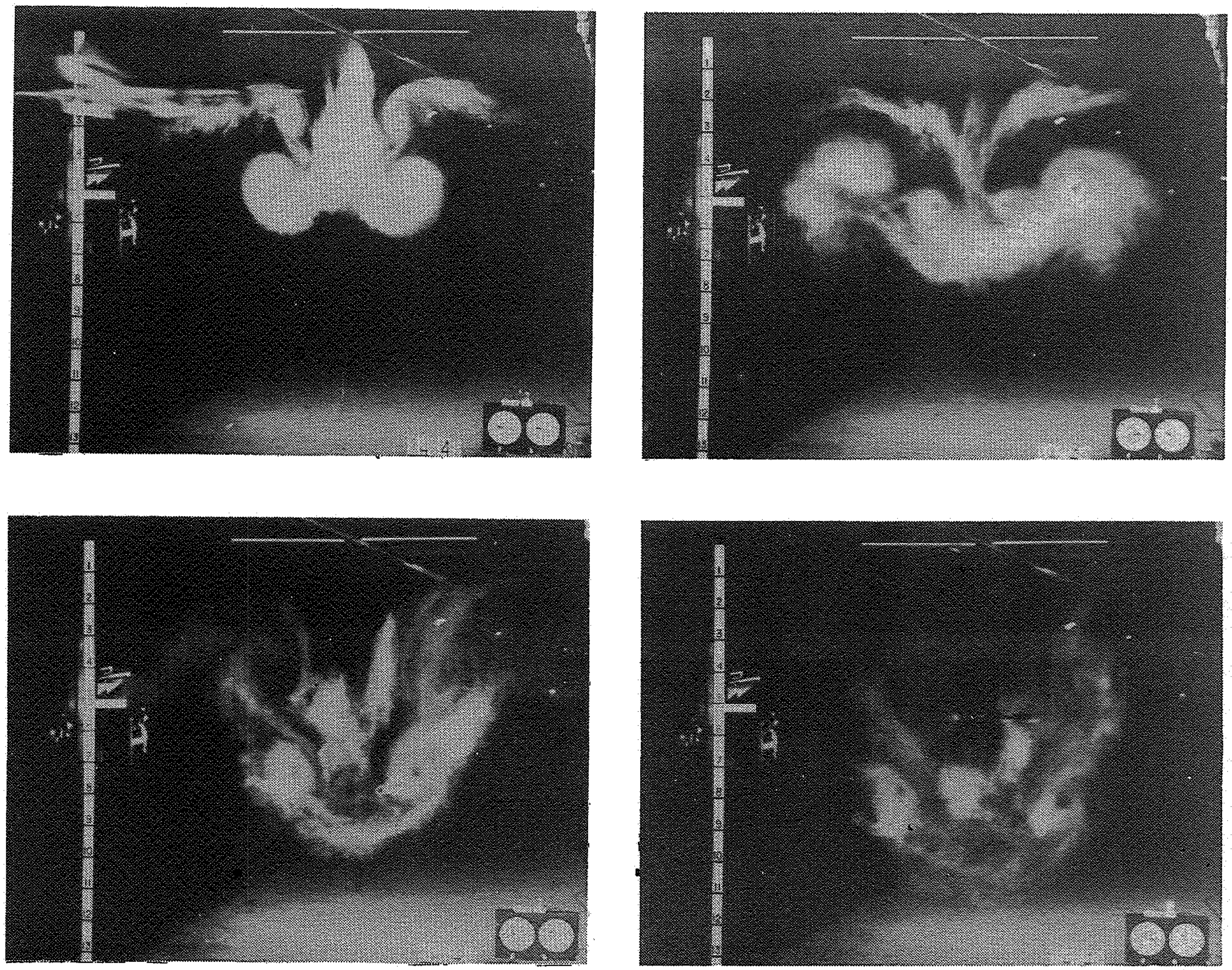

Figure 10.--Lift-induced vortex system created by 0 03-scale model of the wide-body jet transport aircraft (inboard flaps deflected 30°). Photographic sequence rate corresponds to a separation distance of 0 54 km. Following model is centered in vortex in last photograph. Lift coefficient = 1.20; velocity = 30.48 m/s.

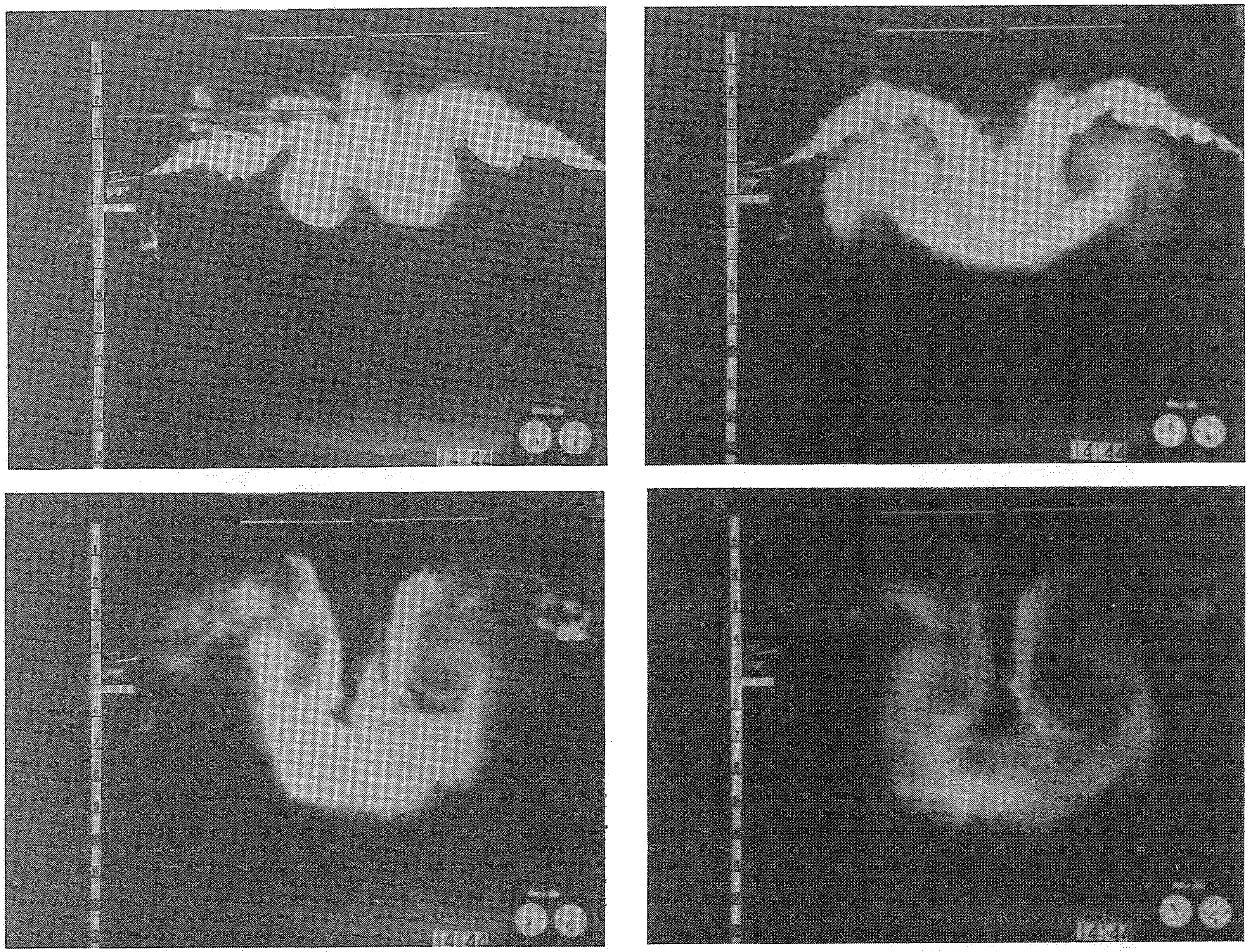

Figure 11.—Effect of maximum engine thrust on (fig 10) vortex system of wide-body jet transport aircraft model (inboard flaps deflected 30°).