N71-13763
TMX-2146

NASA TECHNICAL MEMORANDUM

NASA TM X-2146

NASA TM X-2146

CASE FILE COPY

A COMPARISON OF SPHERICAL AND TRIANGULAR BOUNDARY-LAYER TRIPS ON A FLAT PLATE AT SUPERSONIC SPEEDS

by Raymond M. Hicks and William R. Harper, Jr.

Ames Research Center
Moffett Field, Calif. 94035

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • DECEMBER 1970

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM X-2146		

4. Title and Subtitle	5. Report Date
A COMPARISON OF SPHERICAL AND TRIANGULAR BOUNDARY–LAYER TRIPS ON A FLAT PLATE AT SUPERSONIC SPEEDS	December 1970
	6. Performing Organization Code
7. Author(s) Raymond M. Hicks and William R. Harper, Jr.	8. Performing Organization Report No. A-3722
	10. Work Unit No. 126-13-10-10-00-21
9. Performing Organization Name and Address NASA Ames Research Center Moffett Field, Calif., 94035	11. Contract or Grant No.
	13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C., 20546	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

An experimental investigation was conducted in the Ames 1- by 3-Foot Supersonic Wind Tunnel using spherical and triangular protuberances to promote artificial boundary-layer transition from laminar to turbulent flow on a flat plate. The location of the trips varied from 0.08 in. to 1.0 in. from the leading edge. The free-stream Mach numbers of the test were 1.58, 2.17, and 2.91. At Mach numbers of 1.58 and 2.17, the spherical trips had a nominal diameter of 0.01 in. while the triangular trips had a height of 0.0073 in. At a Mach number of 2.91, 0.015-in. (nom.) dia. spheres and 0.0146-in.-high triangles were used. The relative effect of the spherical and triangular trips was studied by varying unit Reynolds number over a range at each Mach number. The sublimation technique was used exclusively in the investigation to determine the location of transition.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Boundary-layer tripping	Unclassified – Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	40	$3.00

*For sale by the National Technical Information Service, Springfield, Virginia 22151

NOTATION

k	trip height, in.
M	free-stream Mach number
R	free-stream unit Reynolds number
R_k	free-stream unit Reynolds number multiplied by trip height (trip Reynolds number)
$R_{k_{eff}}$	minimum trip Reynolds number that produces artificial transition near the trip position
R_x	free-stream unit Reynolds number multiplied by trip position (station Reynolds number)
x	trip location relative to leading edge of plate (station), in.
x_t	distance from the leading edge of the plate to transition, in.
δ	boundary-layer thickness, in.

A COMPARISON OF SPHERICAL AND TRIANGULAR BOUNDARY–LAYER TRIPS ON A FLAT PLATE AT SUPERSONIC SPEEDS

Raymond M. Hicks and William R. Harper, Jr.

Ames Research Center

SUMMARY

An experimental investigation was conducted in the Ames 1- by 3-Foot Supersonic Wind Tunnel using spherical and triangular protuberances to promote artificial boundary-layer transition from laminar to turbulent flow on a flat plate. The location of the trips varied from 0.08 in. to 1.0 in. from the leading edge. The free-stream Mach numbers of the test were 1.58, 2.17, and 2.91. At Mach numbers of 1.58 and 2.17, the spherical trips had a nominal diameter of 0.01 in. while the triangular trips had a height of 0.0073 in. At a Mach number of 2.91, 0.015-in. (nom.) dia. spheres and 0.0146-in.-high triangles were used. The relative effect of the spherical and triangular trips was studied by varying unit Reynolds number over a range at each Mach number. The sublimation technique was used exclusively in the investigation to determine the location of transition.

The results of this investigation showed that artificial transition from laminar to turbulent flow could be achieved at a lower trip Reynolds number if triangular instead of spherical trips were used. It also was found that a larger particle (sphere or triangle) is required to produce artificial transition near the trip position as the distance from the leading edge is increased from 0.08 in. to 1.0 in.

INTRODUCTION

When testing airplane configurations in wind tunnels, it often is desirable to duplicate the boundary-layer flow conditions anticipated on the aircraft in flight. In many cases, this means that relatively large regions of laminar flow found on wind-tunnel models but not on the airplane in flight must be replaced by turbulent flow. There are several methods of establishing fully turbulent flow on wind-tunnel models, including air injection, heat, sound, and distributed roughness bands, the last of which is the most readily available technique at present. Whatever the method, it is important to create turbulent flow with characteristics (e.g., velocity profile) similar to those of natural turbulence, thus minimizing changes in the aerodynamic coefficients of the wind-tunnel model from those that would be obtained with a naturally turbulent boundary layer.

Since the transition from laminar to turbulent flow has been shown to be associated with the formation and subsequent collapse of a three-dimensional field of vorticity, it is desirable to select roughness particles that are most efficient in the generation of vorticity. In water-tunnel tests, triangular particles oriented so that the apex of the triangle points into the flow proved to be effective vortex generators (ref. 1). Van Driest's classical experiments on a cone (refs. 2 and 3) have shown that spherical roughness particles also are responsible for the formation of vorticity.

The purpose of the investigation reported here is to compare the transition behind spherical and triangular boundary-layer trips on a flat plate at supersonic speeds. Results are evaluated against the criteria established by Braslow (ref. 4).

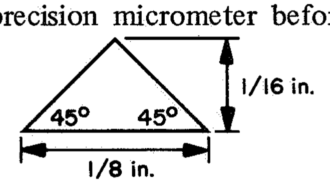
MODEL DESCRIPTION AND TEST PROCEDURE

The flat plate used in the present investigation is shown in figure 1. The spherical and triangular trips were positioned on the flat plate as shown in figure 2 (except for a spacing study). Both the spherical and triangular trips were placed on the plate 1 in. apart, thereby preventing interaction of the fields of vorticity emanating from adjacent particles. Test variables are given in table 1.

TABLE 1.– RANGE OF TEST VARIABLES

Trip	Height, in.	Mach number	Station, in.	Reynolds number per in.
Triangle	0.0073	1.58	0.08 to 1.0	137,000 to 479,000
Triangle	0.0073	2.17	0.08 to 1.0	137,000 to 685,000
Triangle	0.0146	2.91	0.08 to 1.0	205,000 to 685,000
Sphere	0.01(nom.)	1.58	0.08 to 1.0	100,000 to 500,000
Sphere	0.01(nom.)	2.17	0.08 to 1.0	100,000 to 600,000
Sphere	0.015(nom.)	2.91	0.08 to 1.0	192,000 to 640,000

The spherical trips were "accurately" ground chrome steel ball bearings, each measured with a precision micrometer before mounting. The amount of cement used was carefully controlled to preserve as nearly as possible the spherical shape of the mounted trips. The triangular trips were cut from pressure-sensitive tape with a uniform thickness of 0.0073 in. Each triangular trip was a right triangle with the nominal dimensions shown in sketch (a). The right angle pointed into the flow.



Sketch (a)

Before each run the plate was sprayed with a mixture of fluorene and petroleum ether. During the run, sublimation of the residual flourene after evaporation of the petroleum ether showed the position of transition. The collapse of vorticity was indicated on the sublimation pattern by the appearance of the classical turbulent wedge at the start of transverse contamination. The distance from the leading edge of the plate to the formation of the turbulent wedge was measured during the wind-on condition by use of a cathetometer mounted outside the wind tunnel (fig. 3). Typical sublimation pictures are shown in figure 4 (the dark region in the upper left hand corner of the plate is a shadow cast by the window frame). In figure 4(a), trips were ineffective in fixing transition near the trip position, while in figure 4(b) the transition is fixed near the trip position. The arrows indicate the position of transition as determined by means of the cathetometer during the run. The 1-in. spacing between trips used in this investigation made it possible to acquire six times the data that could be obtained with a single row of closely spaced particles placed the same distance from the leading edge. A spacing study, to be discussed later, was conducted to establish a lower bound on spacing below which the measurements of transition location obtained in this investigation would be invalid.

RESULTS AND DISCUSSION

The distance to transition x_t for zero pressure gradient flow can be written using functional notation as

$$x_t = f_1(k,\ x,\ M,\ \text{free-stream turbulence})$$

or in terms of Reynolds numbers

$$x_t = f_2(R_k,\ R_x,\ M,\ \text{free-stream turbulence}) \tag{1}$$

In order to limit the number of variables to R_k, R_x, and Mach number, it is necessary to position the particles well ahead of the location of natural transition, thus reducing the effect of free-stream turbulence to a negligible level. Plots of x_t versus R_k (fig. 5) show that natural transition took place considerably downstream from the positions of the boundary-layer trips (the abscissas for the curves of natural transition are the product of unit Reynolds number times spherical trip height). These figures also give an indication of the relative effect of the spherical and triangular trips. (In this report trips are considered effective when the measurements to the start of transverse contamination fall on the plateau region, which appears at an almost constant distance behind the trip position in fig. 5.) A direct comparison of minimum effective trip Reynolds number for the two types of trips cannot be made from these figures since the station Reynolds number is different at the minimum effective trip Reynolds number for each type of trip. Note that for all Mach numbers and stations, the triangular trips become effective at a lower trip Reynolds number than the spherical trips.

Figure 6 compares the spheres of 0.015-in. nominal diameter and triangular trips of 0.0146-in. height at the same value of trip Reynolds number. Note that transverse contamination begins farther upstream for the triangular trips than for the spherical trips at all stations. It is worth noting that when the trips are effective there still remains a finite distance between the trip position and the start of transverse contamination. In fact, it appears that it may be impossible to bring transition completely forward to the trip position without causing large distortion of the boundary layer; this phenomenon has been recognized by many previous investigators (e.g., ref. 3).

The minimum value of trip Reynolds number that brings transition forward to the plateau region shown in figure 5 is defined as $R_{k_{eff}}$. Summary plots of this quantity as a function of station were derived as follows for each Mach number. First, it is necessary to develop a functional relation (from equation (1)) so that the summary curves account for the important parameters involved. For negligible effects of free-stream turbulence, figure 5 shows that equation (1) can be written

$$x_t - x = f_3(R_x,\ R_k,\ M)$$

Then, for a constant Mach number

$$x_t - x = f_4(R_k,\ R_x)$$

or equivalently,

$$x_t - x = f_5(x/k, R_k)$$

For effective tripping, the location of transition is a constant distance downstream of the trip position. Hence, we can write

$$x_t - x = f_5(x/k, R_k) = \text{constant}$$

and therefore

$$R_{k_{eff}} = f_6(x/k)$$

This is the form of the summary plots shown in figure 7. Note that as the distance from the leading edge is increased, it becomes necessary to use a larger trip Reynolds number to fix transition near the trip position, the rate of increase in effective trip Reynolds number being about the same for either the spherical or triangular trips. As shown in figures 6 and 8, the triangle at the 0.08-in. station is effective for $M = 2.17$ and $M = 2.91$ while the triangles at the other stations become less effective as the distance from the leading edge is increased. The spheres are less effective than the triangles at all stations.

Figure 9 compares the height of the trips relative to the boundary-layer thickness when effective tripping is achieved. It can be seen that it is necessary to use a particle of a height greater than the boundary-layer thickness for Mach numbers from 1.58 to 2.91 if the trips are placed within 1 in. of the leading edge on a flat plate with zero leading-edge sweep. However, the height of the triangular particle required for effective tripping is less than the diameter of the spherical trips. An extrapolation of the curves shown in figure 9 to a larger value of x/k indicates that it may be possible to realize effective tripping with a particle completely immersed in the boundary layer for the test Mach number range if the trips are placed farther downstream on the plate. This question is mainly academic, however, since trips are seldom placed at distances greater than 1 in. from the leading edge on wind-tunnel models. The boundary-layer thickness used in the ratio of δ/k in figure 9 is theoretical.

Braslow (ref. 4) indicates that for particles with heights within the linear range of the velocity profile, a trip Reynolds number of 600 will cause the first appearance of turbulent spots at the trip position and a slight increase in trip Reynolds number will fix transition very near the roughness particles. The data in figures 7 and 9 show that under the test conditions it was not possible to fix transition near the trip position with a particle immersed in the boundary layer or with an effective trip Reynolds number near 600. However, the trend of effective trip Reynolds number with Mach number for either the spherical or triangular trips indicates that the criteria of reference 4 are applicable at subsonic and transonic speeds.

The final part of this investigation was the determination of a lower bound on spacing below which the particles no longer act individually. The photographs in figure 10 indicate the effect of spacing on transition for spheres of 0.015-in. nominal diameter. It can be seen that for spacings of 1 and 2 diameters, transition occurs farther upstream for the row of trips than for the single particle shown below the row of trips. At a spacing of 3 diameters there is good agreement between the single-particle transition location and that of the row of particles. It can be concluded that the measurements of transition location presented in figure 5 are valid for spacings greater than or equal to 3 diameters.

A practical consideration in selecting a tripping device is the ease of application. Here the triangular particles made of adhesive tape have a decided advantage since they adhere to the surface without additional cement. The particle pattern for the triangular trips is more readily repeated than that for a tripping device requiring the application of a bonding agent, the amount of which is likely to vary with each application.

There are five areas requiring further investigation:

1. The amount of distortion of the boundary layer caused by the triangular trips as compared to the spherical trips. (Some recent work related to this problem has been reported in references 5 and 6.)

2. The parasite drag due to the triangular trips as compared to the spherical trips.

3. The effect of leading-edge sweep on the effective trip Reynolds number.

4. The effect of pressure gradient on the effective trip Reynolds number.

5. The application of the results obtained in this investigation to the determination of roughness size required for small-scale wind-tunnel models wherein closer trip spacing will be desired.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., 94035, Sept. 4, 1970

REFERENCES

1. Hagarty, John C.; and Hama, Francis R.: Further Experiments on the Triangular Patch Stimulator. Tech. Note BN–107 (OSR–TN57–616, ASTIA AD 136 005), University of Maryland, The Institute for Fluid Dynamics and Applied Mathematics, 1957.

2. Van Driest, E. R.; and McCauley, W. D.: The Effect of Controlled Three-Dimensional Roughness on Boundary-Layer Transition at Supersonic Speeds. MD59-115 (AFOSR TN–58–176), North American Aviation, Inc., 1958.

3. Van Driest, E. R.; and Blumer, C. B.: Boundary-Layer Transition at Supersonic Speeds – Three Dimensional Roughness Effects (Spheres). SID 61–275 (AFOSR–1493), North American Aviation, Inc., 1961.

4. Braslow, Albert L.; and Knox, Eugene C.: Simplified Method for Determination of Critical Height of Distributed Roughness Particles for Boundary-Layer Transition at Mach Numbers From 0 to 5. NACA TN 4363, 1958.

5. Peterson, John B.: Boundary-Layer Velocity Profiles Downstream of Three-Dimensional Transition Trips on a Flat Plate at Mach 3 and 4. NASA TN D–5523, 1969.

6. Daugherty, James C.; and Hicks, Raymond M.: Measurements of Local Skin Friction Downstream of Grit-Type Boundary-Layer-Transition Trips at $M = 2.17$ and Zero Heat Transfer. AIAA Journal, May 1970.

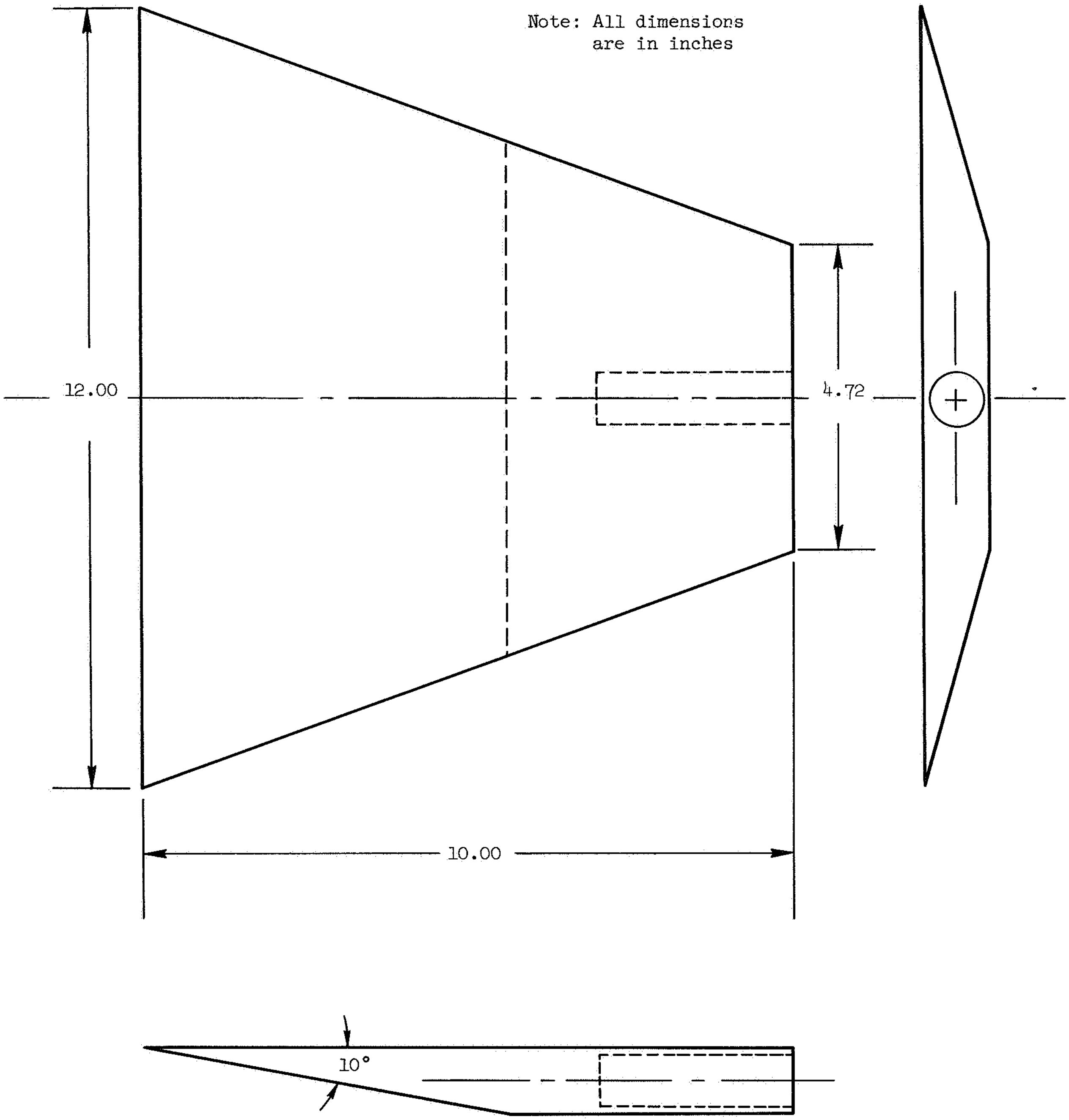


Figure 1.- Flat plate used in boundary layer trip study.

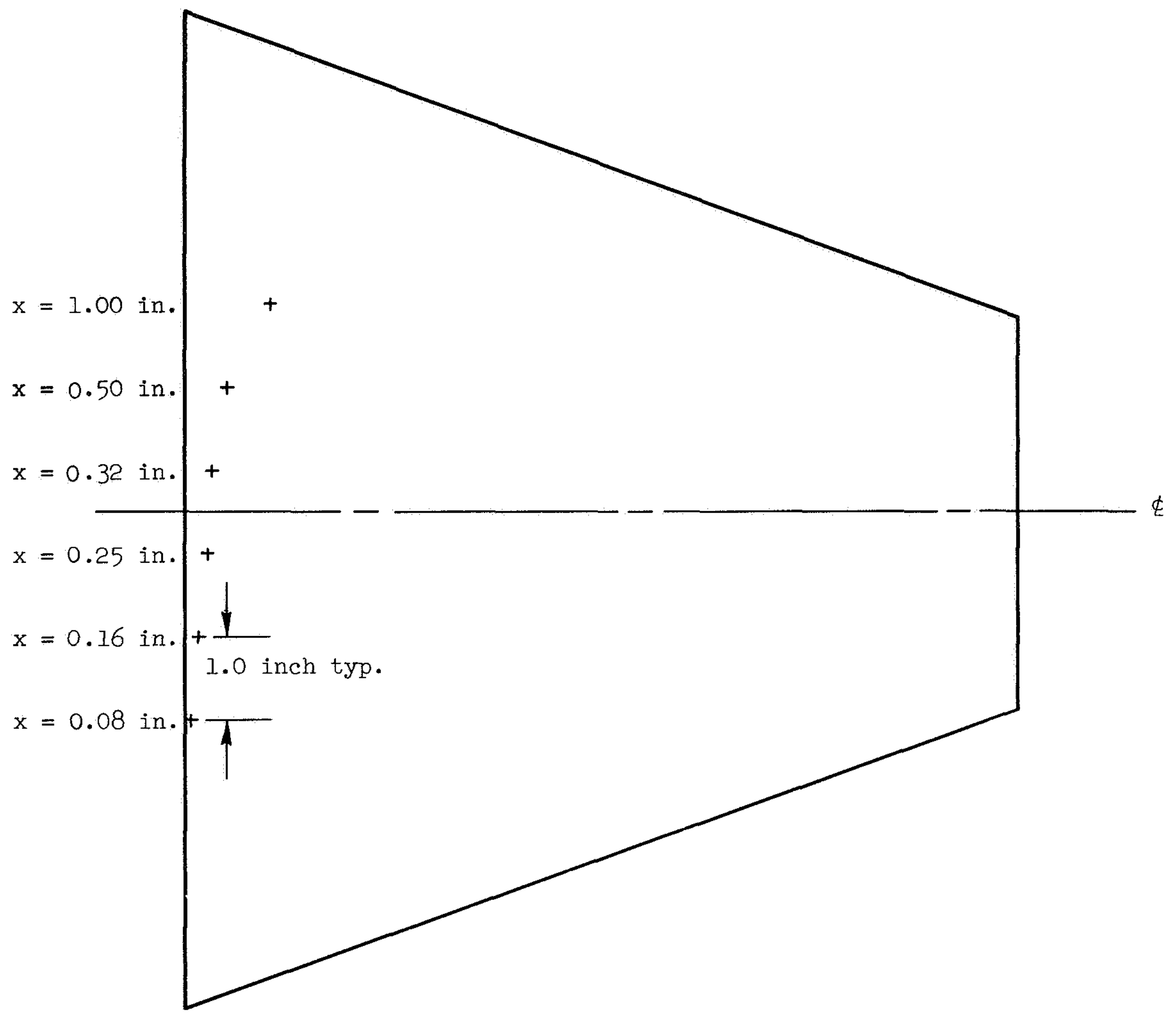


Figure 2.- Positions of spherical and triangular boundary layer trips on flat plate.

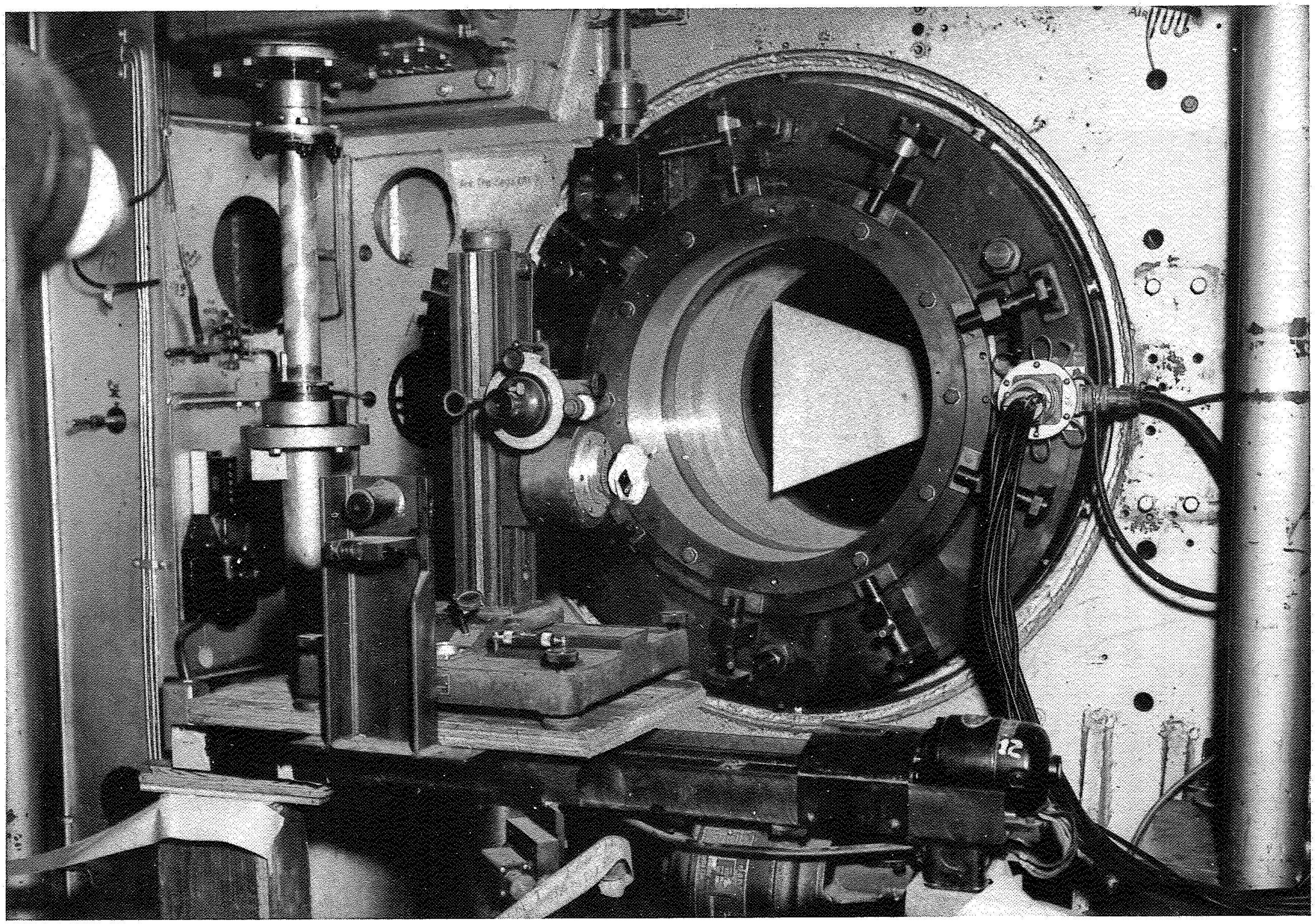
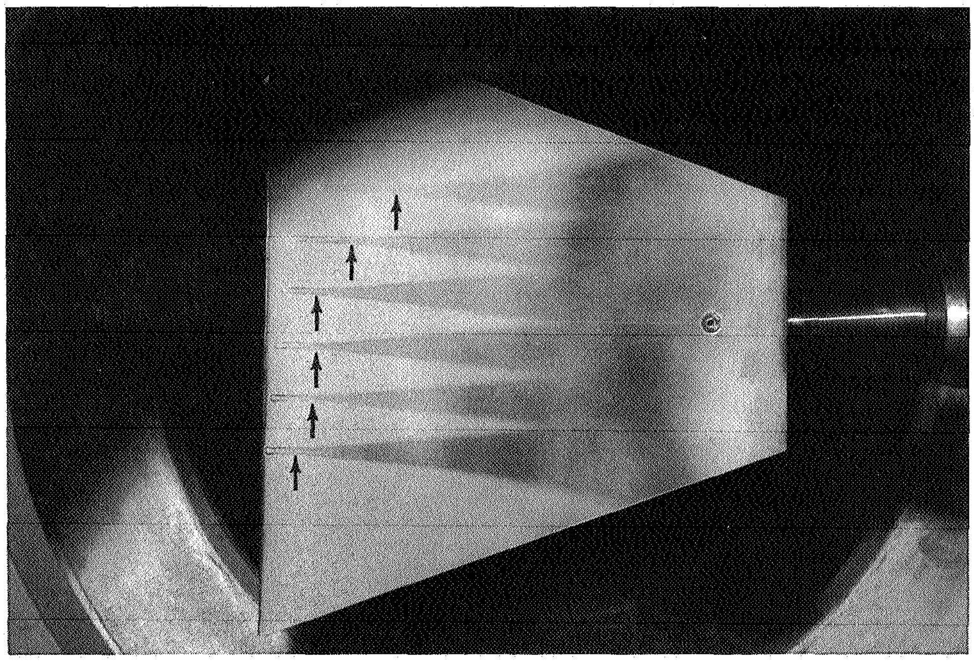
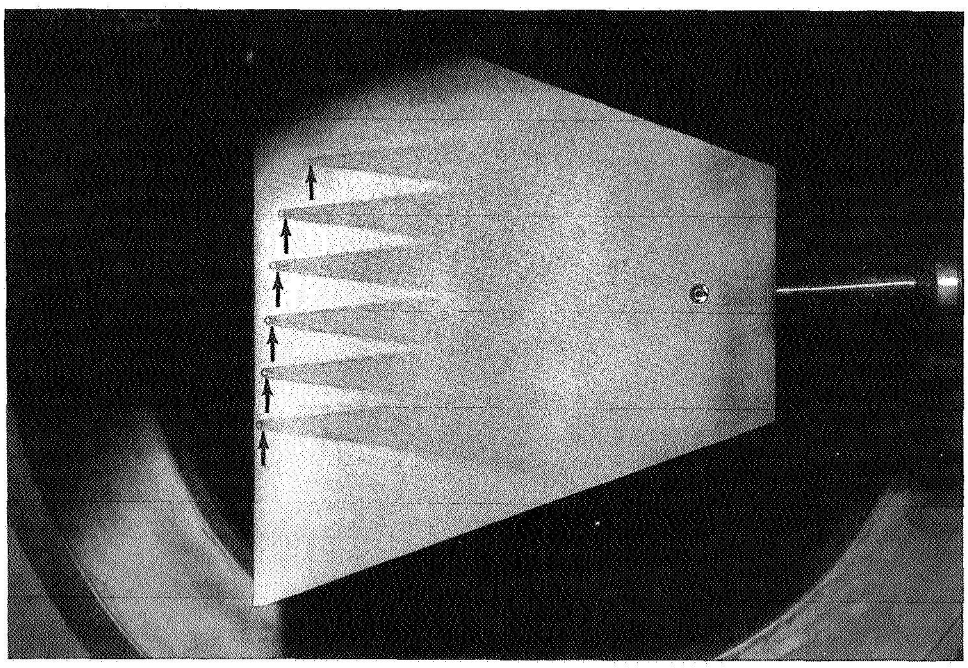


Figure 3.- Photograph showing flat plate mounted in 1-by 3-Foot Wind Tunnel and location of cathetometer used to obtain measurement of x_t.

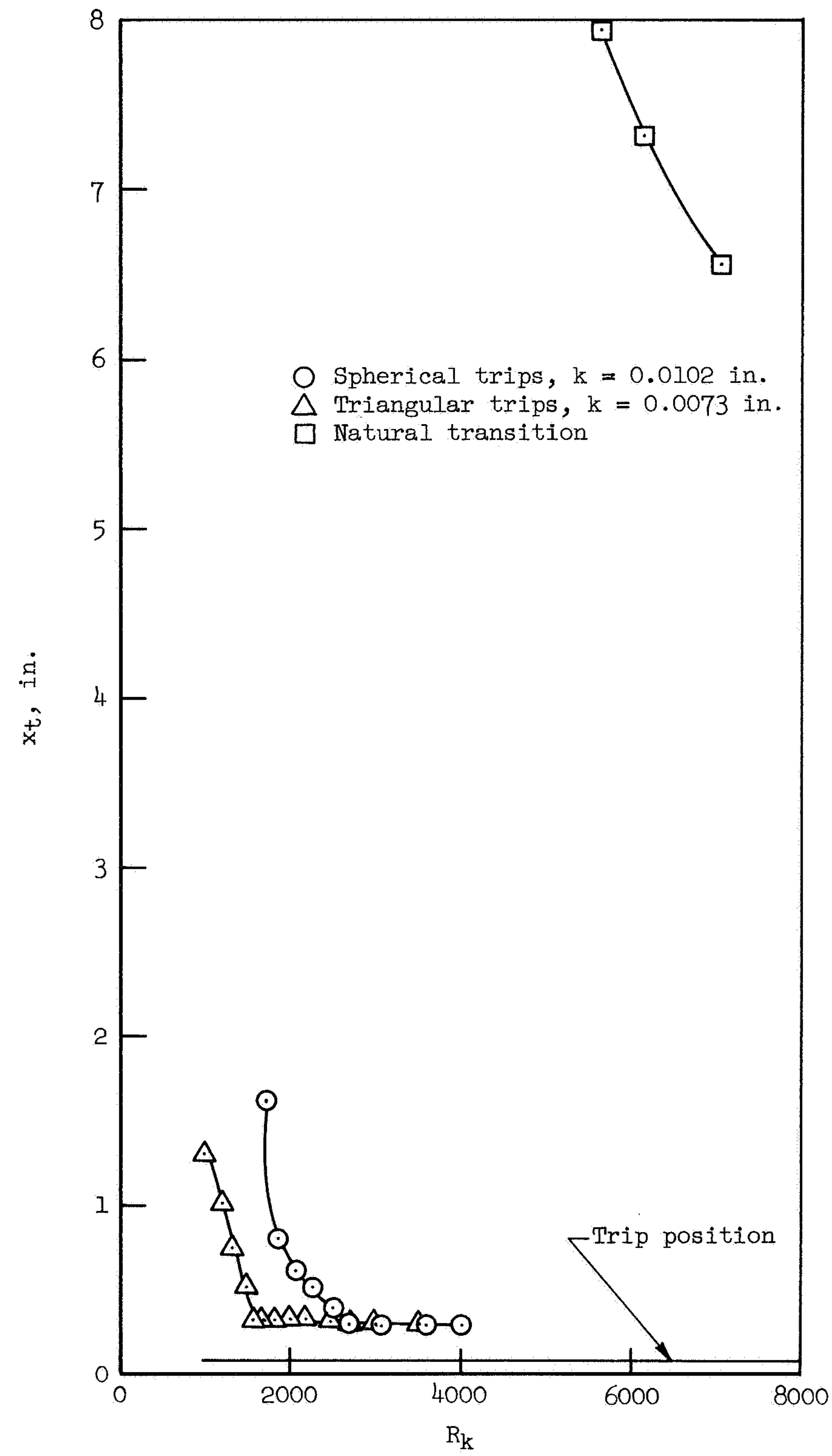


(a) Trips not effective; R_k = 1350.



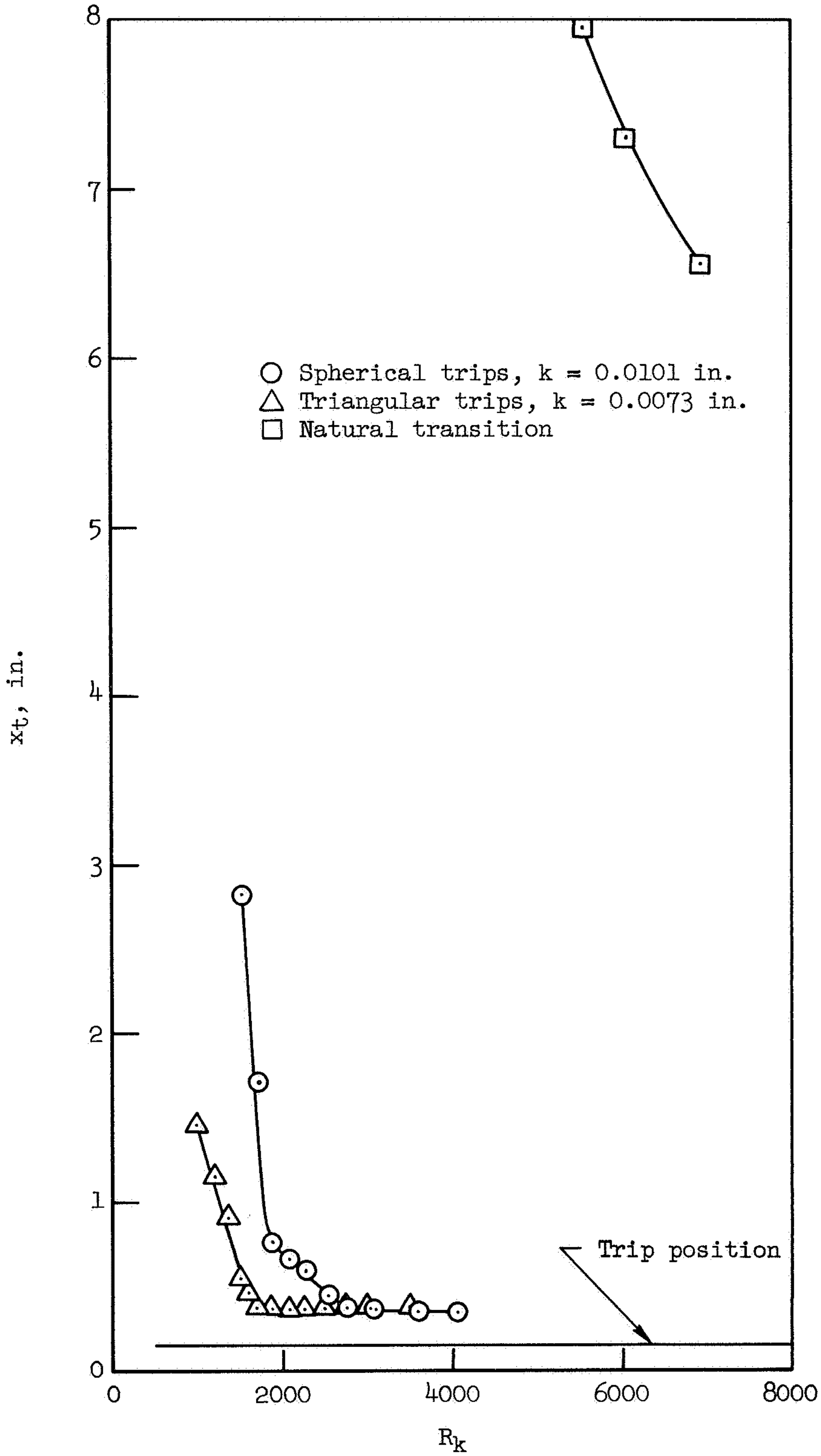
(b) Trips effective; R_k = 3500.

Figure 4.- Typical sublimation photographs showing start of transverse contamination for triangular trips; M = 1.58. Arrows indicate start of transverse contamination as determined by cathetometer readings.



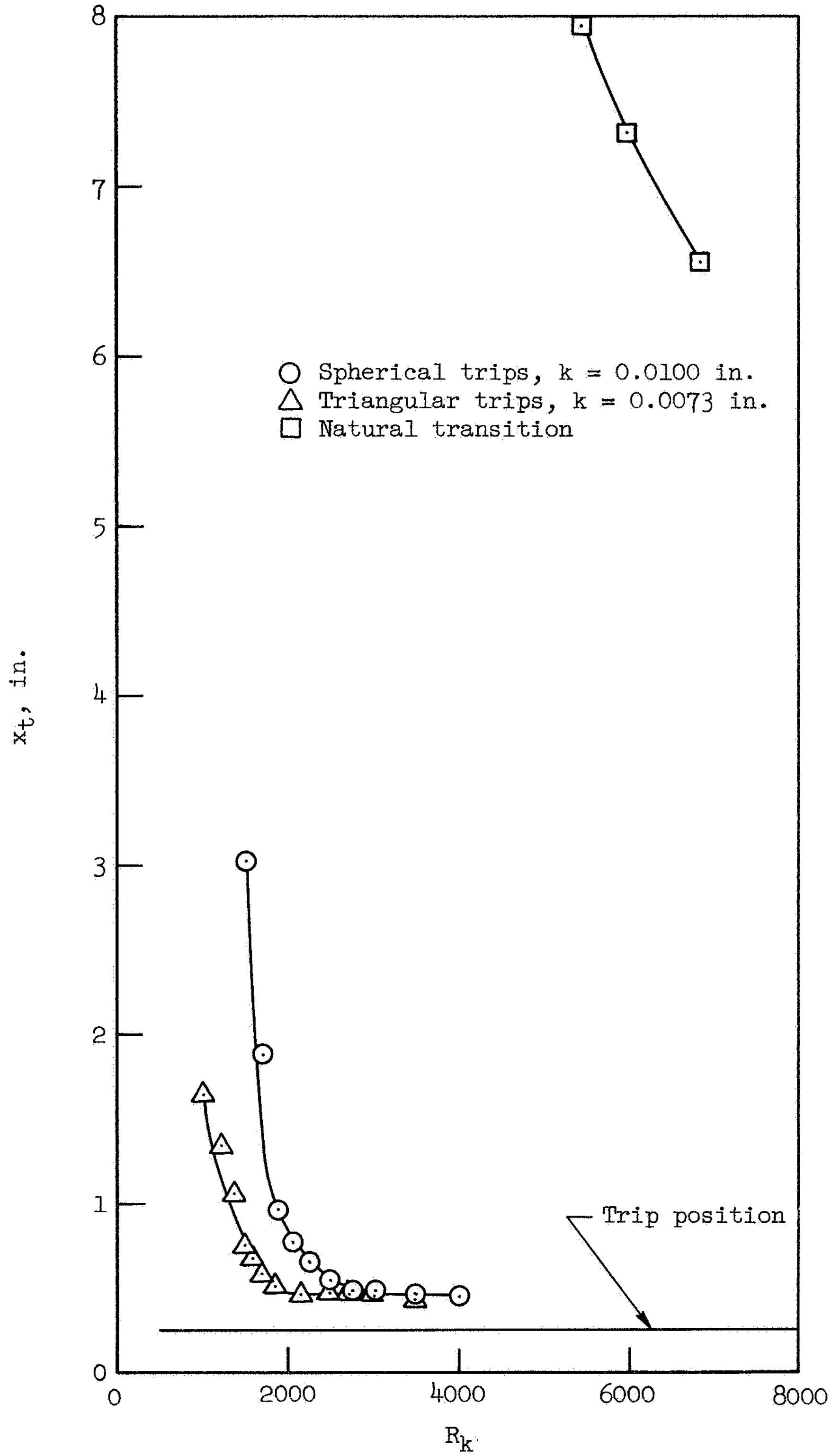
(a) M = 1.58, x = 0.08 in.

Figure 5.- Effect of trip Reynolds number on transition location.



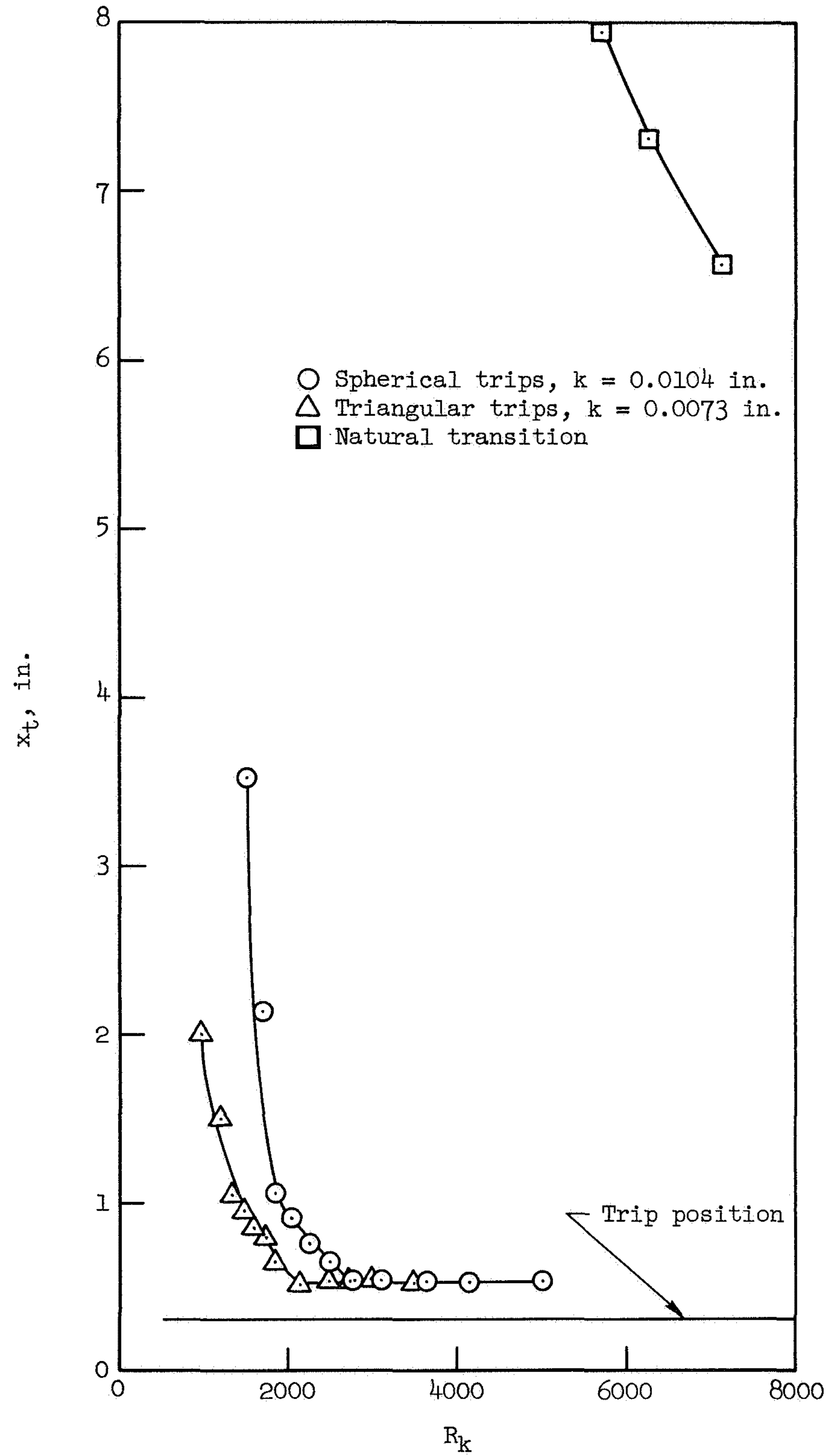
(b) M = 1.58, x = 0.16 in.

Figure 5.- Continued.



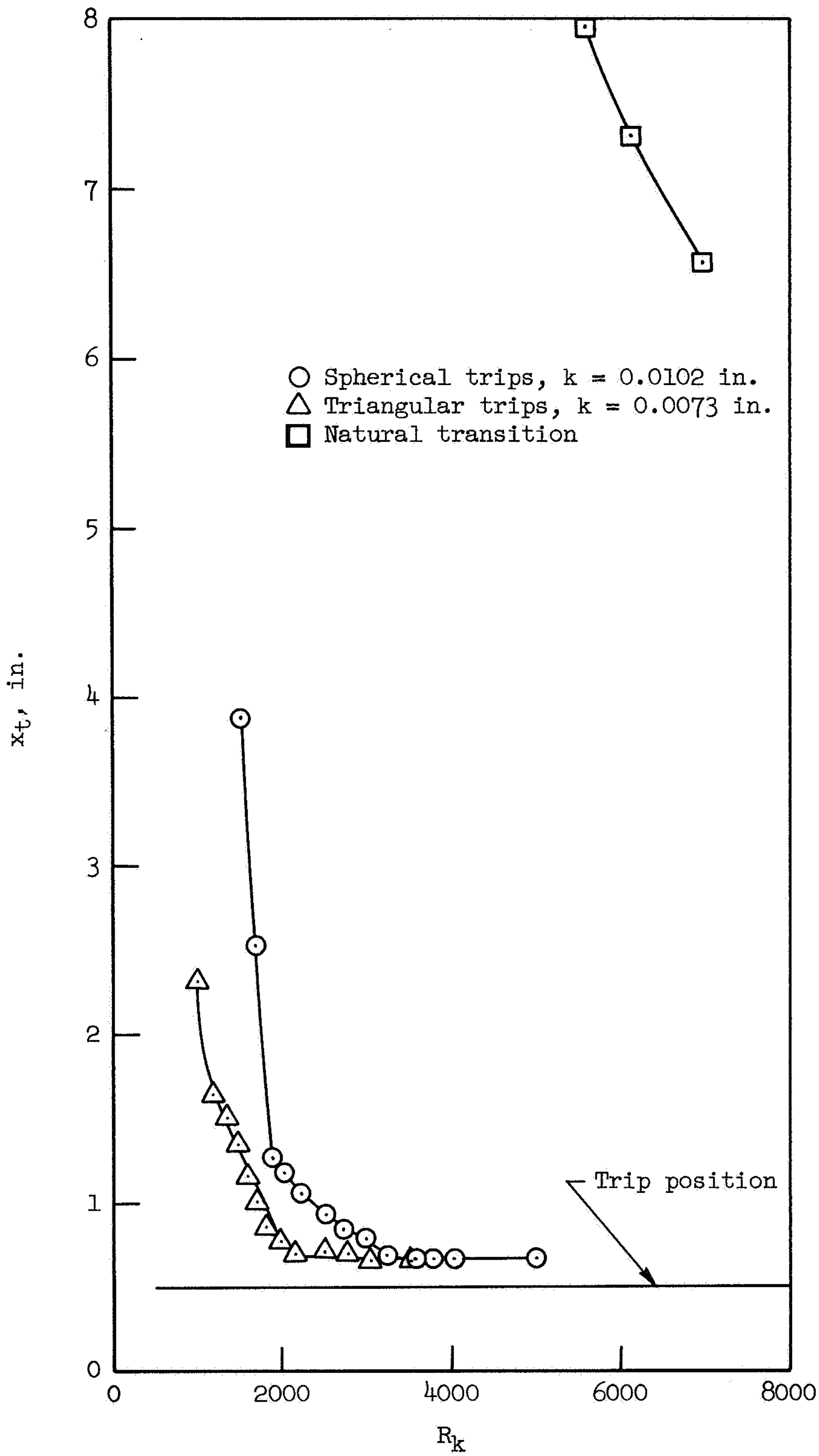
(c) M = 1.58, x = 0.25 in.

Figure 5.- Continued.



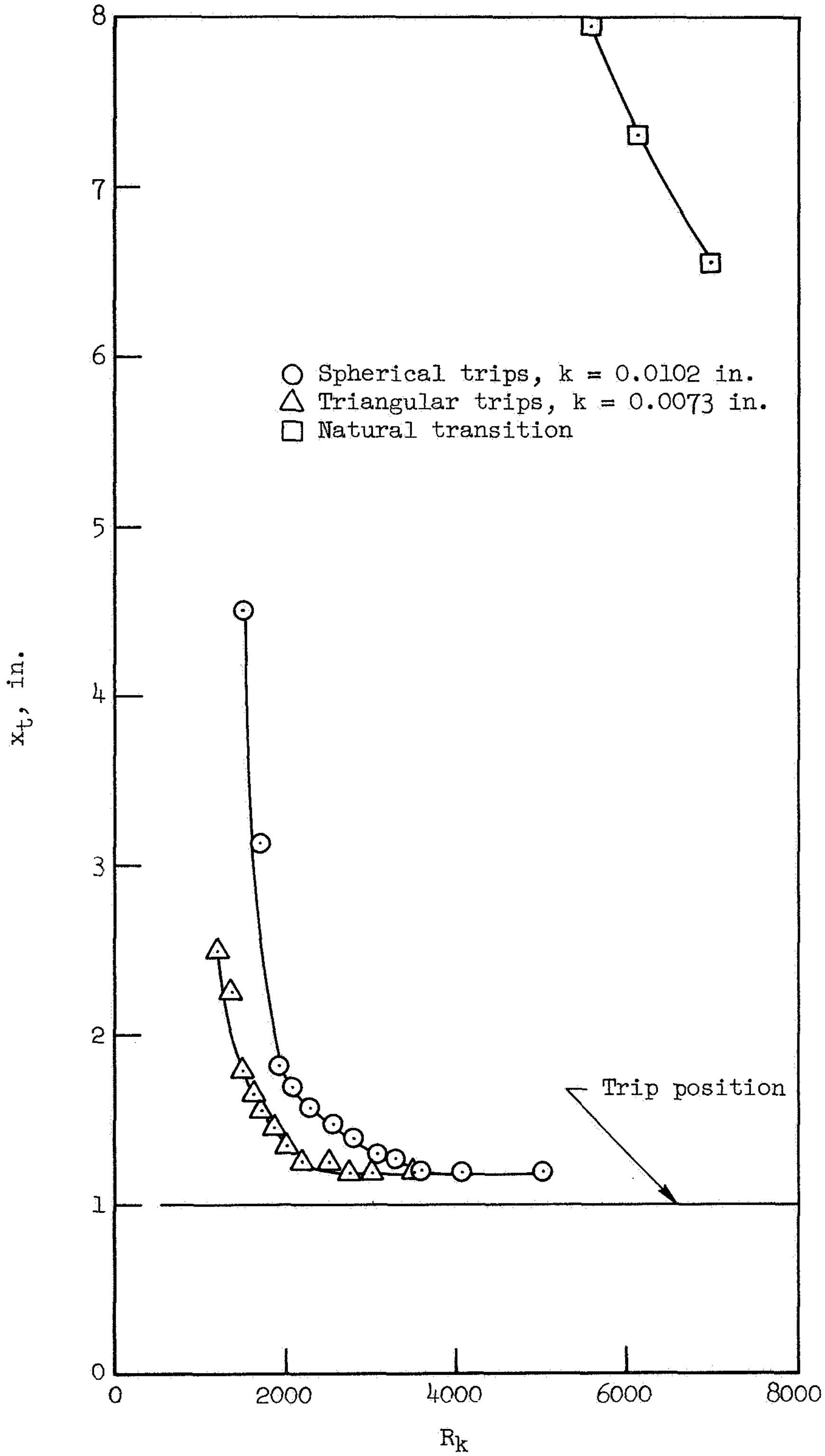
(d) M = 1.58, x = 0.32 in.

Figure 5.- Continued.



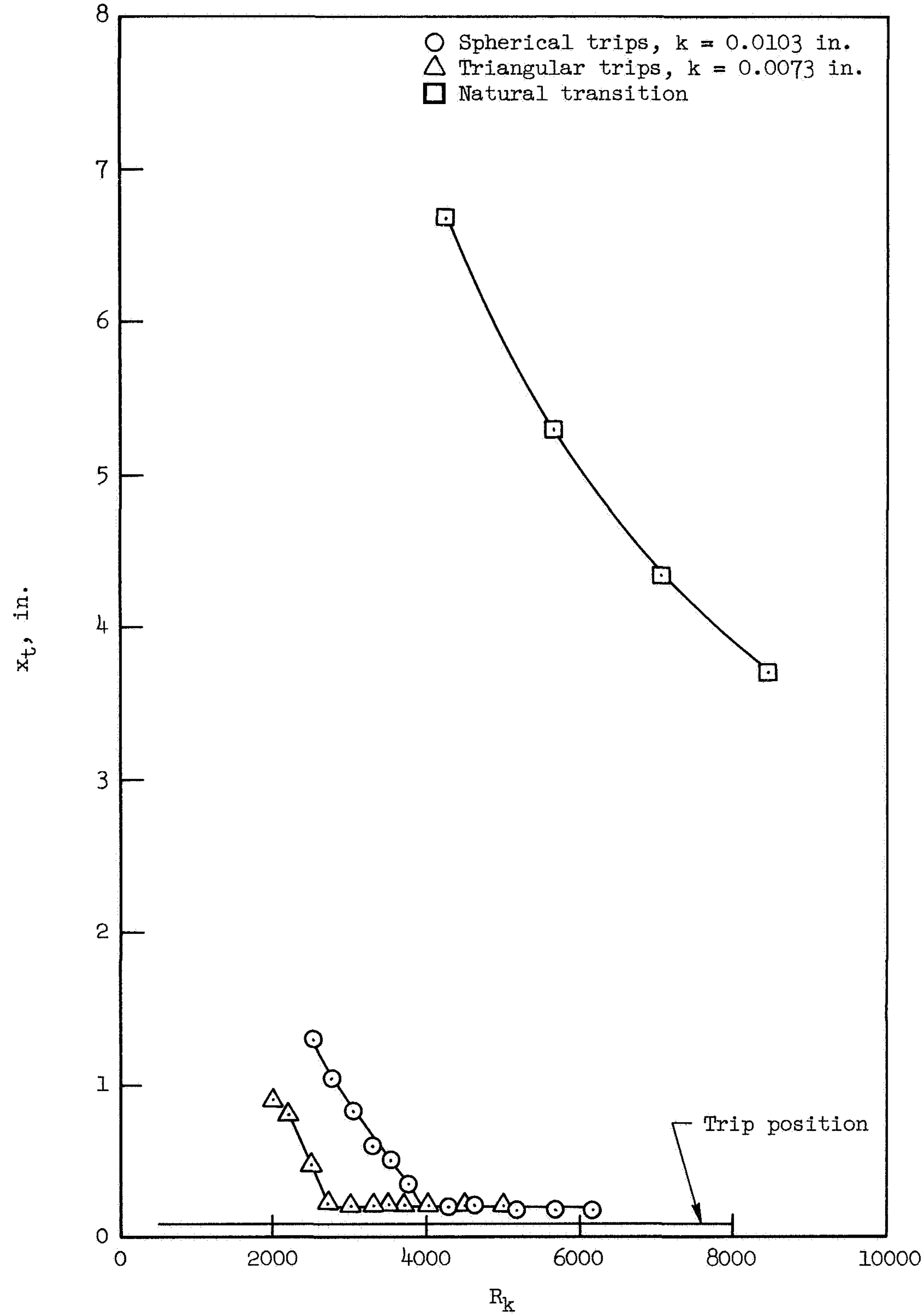
(e) M = 1.58, x = 0.50 in.

Figure 5.- Continued.



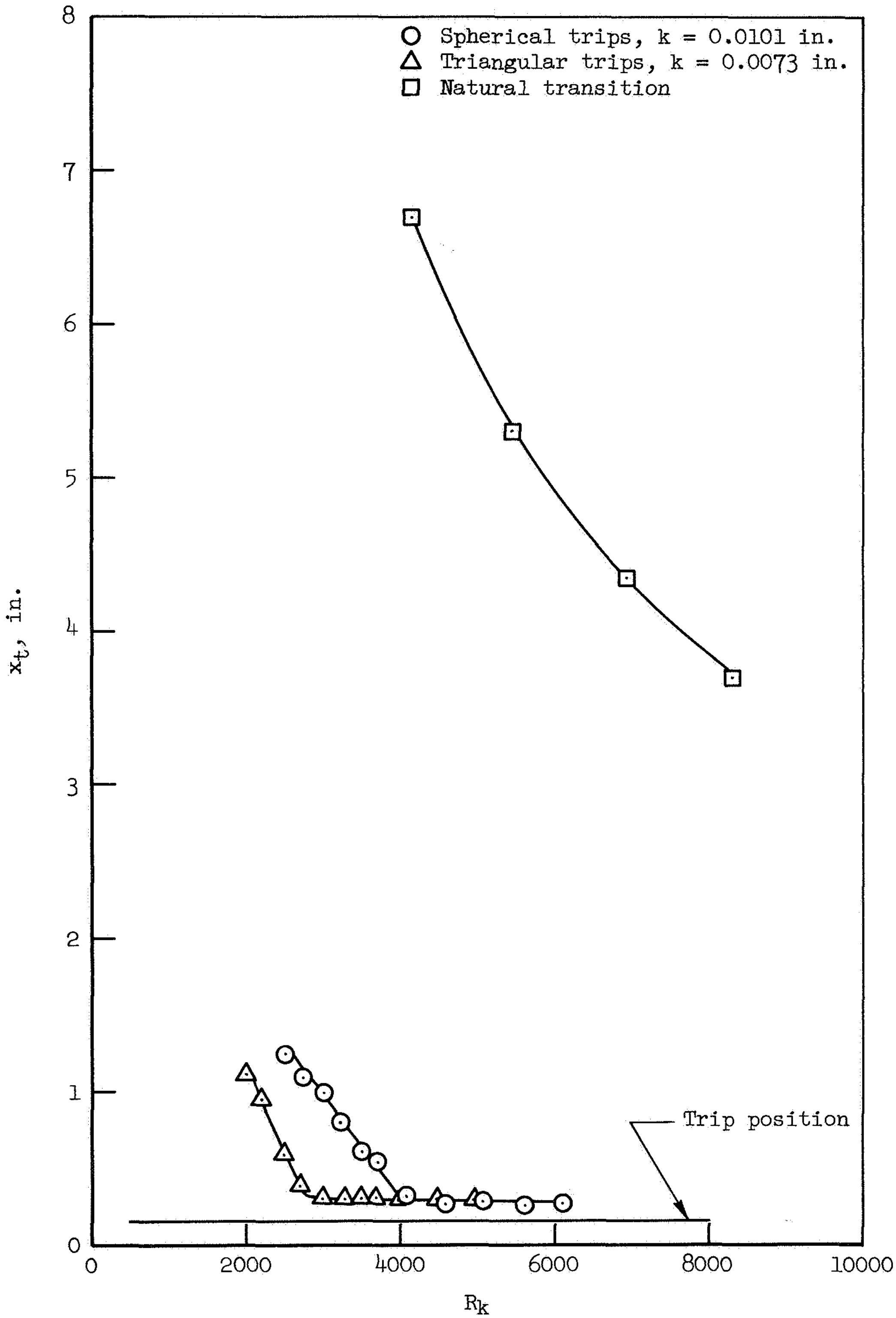
(f) M = 1.58, x = 1.00 in.

Figure 5.- Continued.



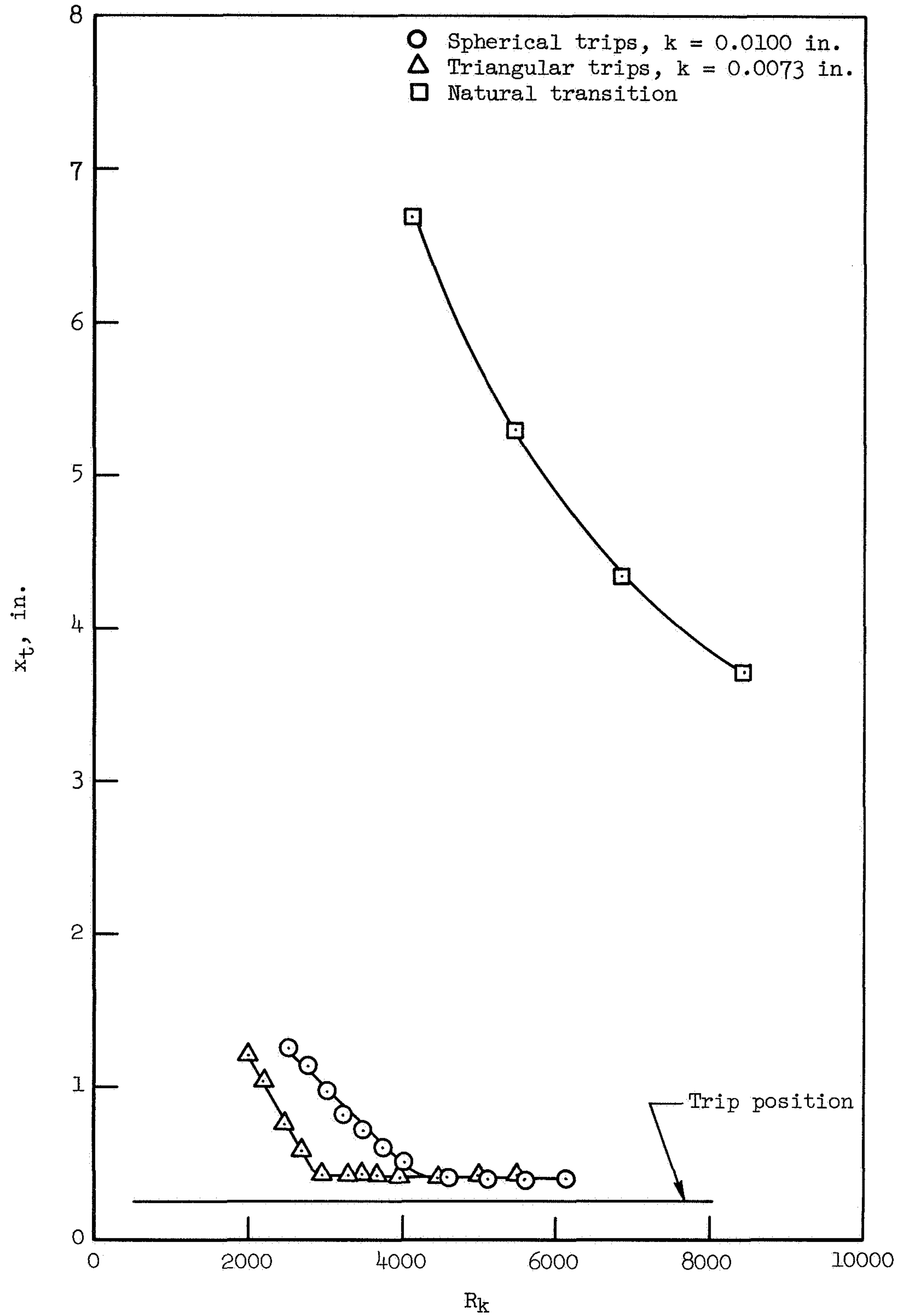
(g) M = 2.17, x = 0.08 in.

Figure 5.- Continued.



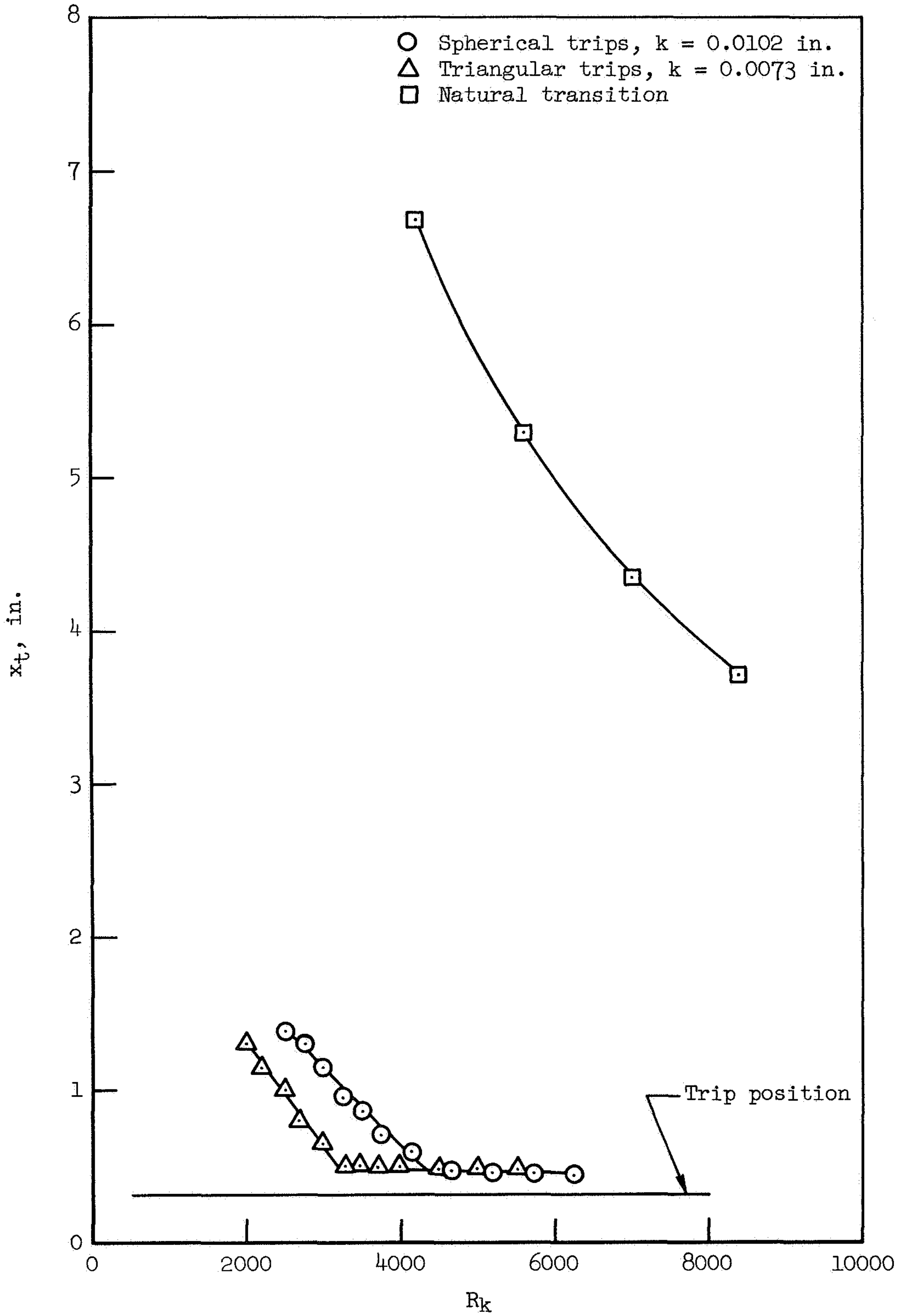
(h) M = 2.17, x = 0.16 in.

Figure 5.- Continued.



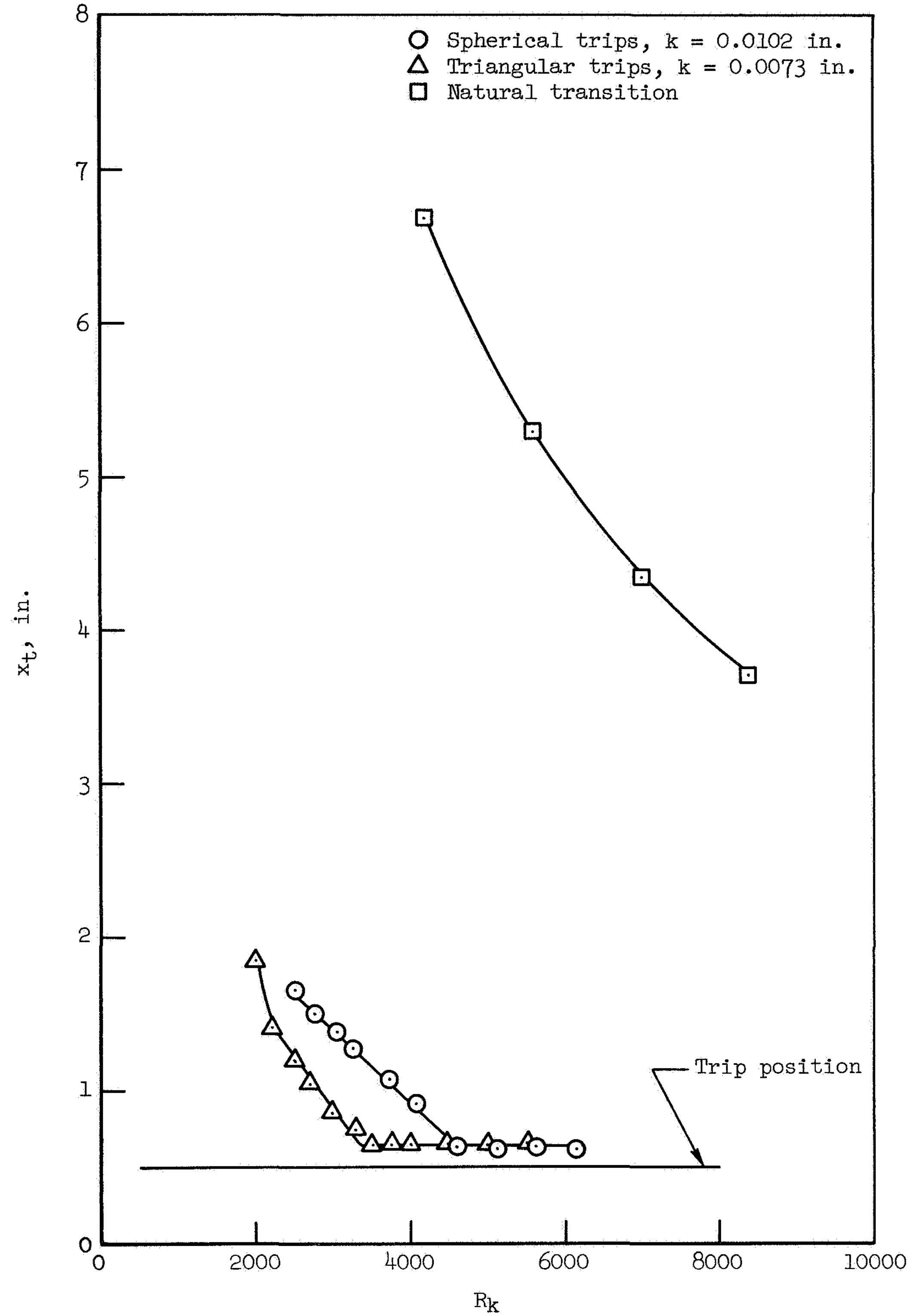
(i) M = 2.17, x = 0.25 in.

Figure 5.- Continued.



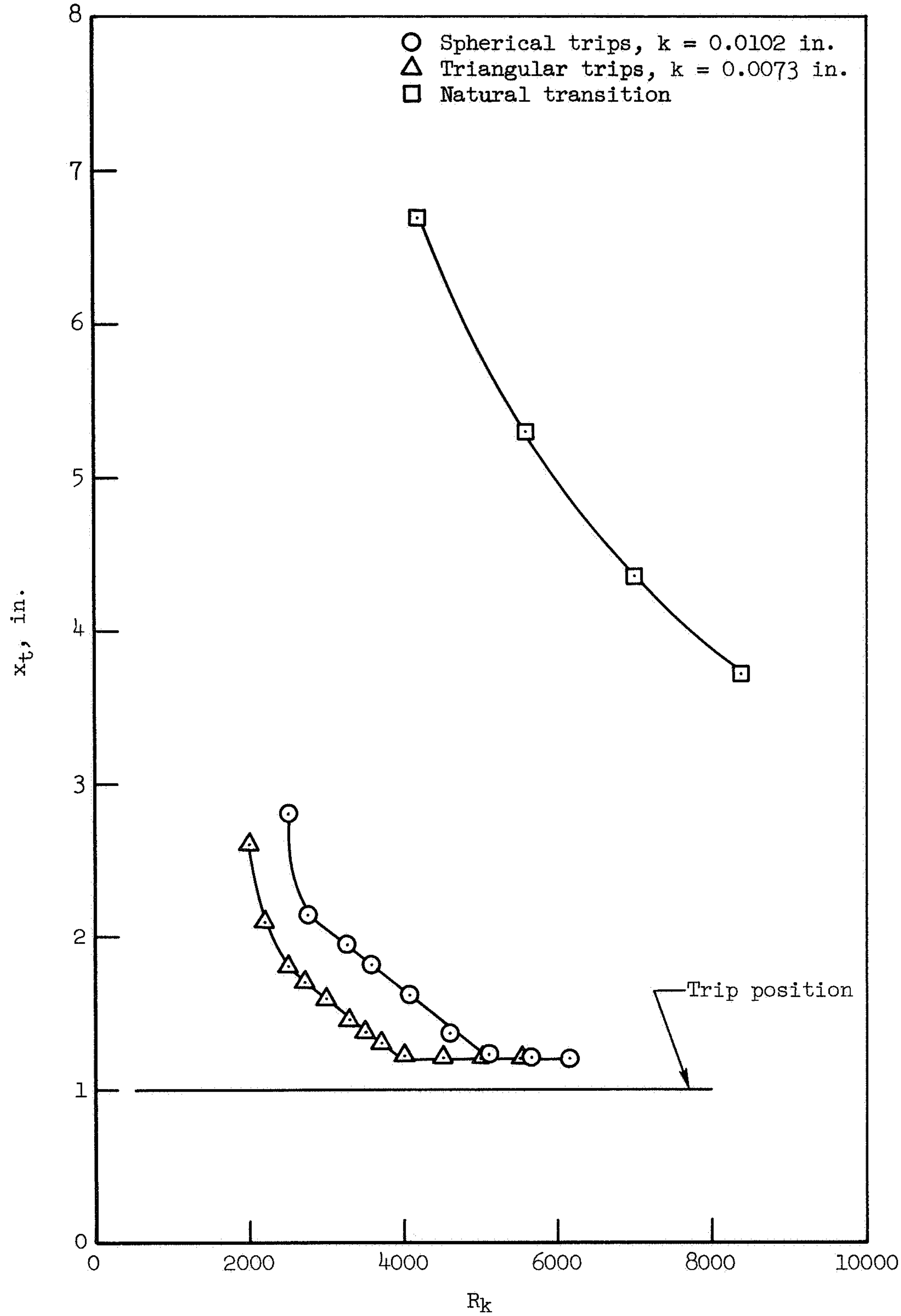
(j) M = 2.17, x = 0.32 in.

Figure 5.- Continued.



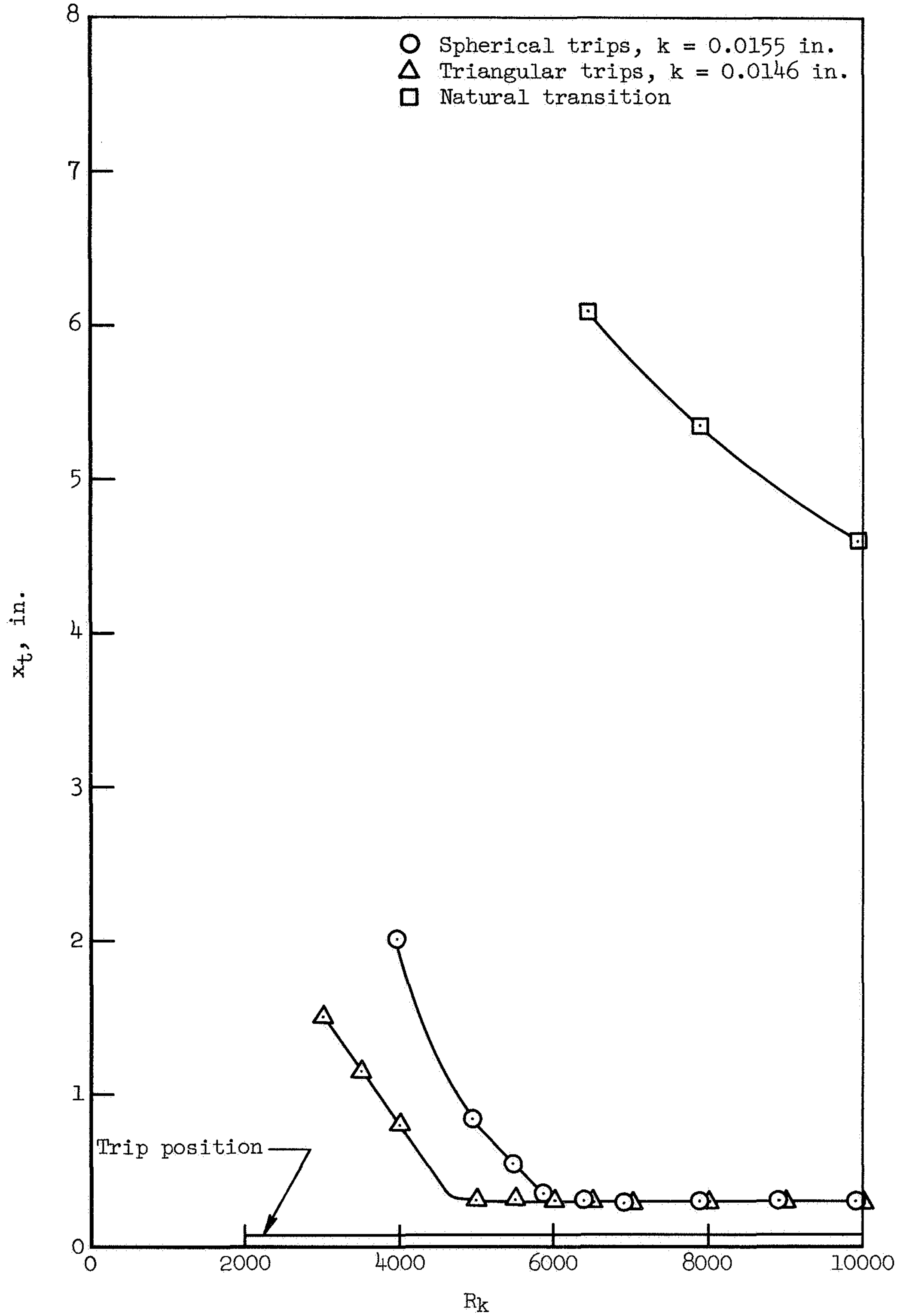
(k) M = 2.17, x = 0.50 in.

Figure 5.- Continued.



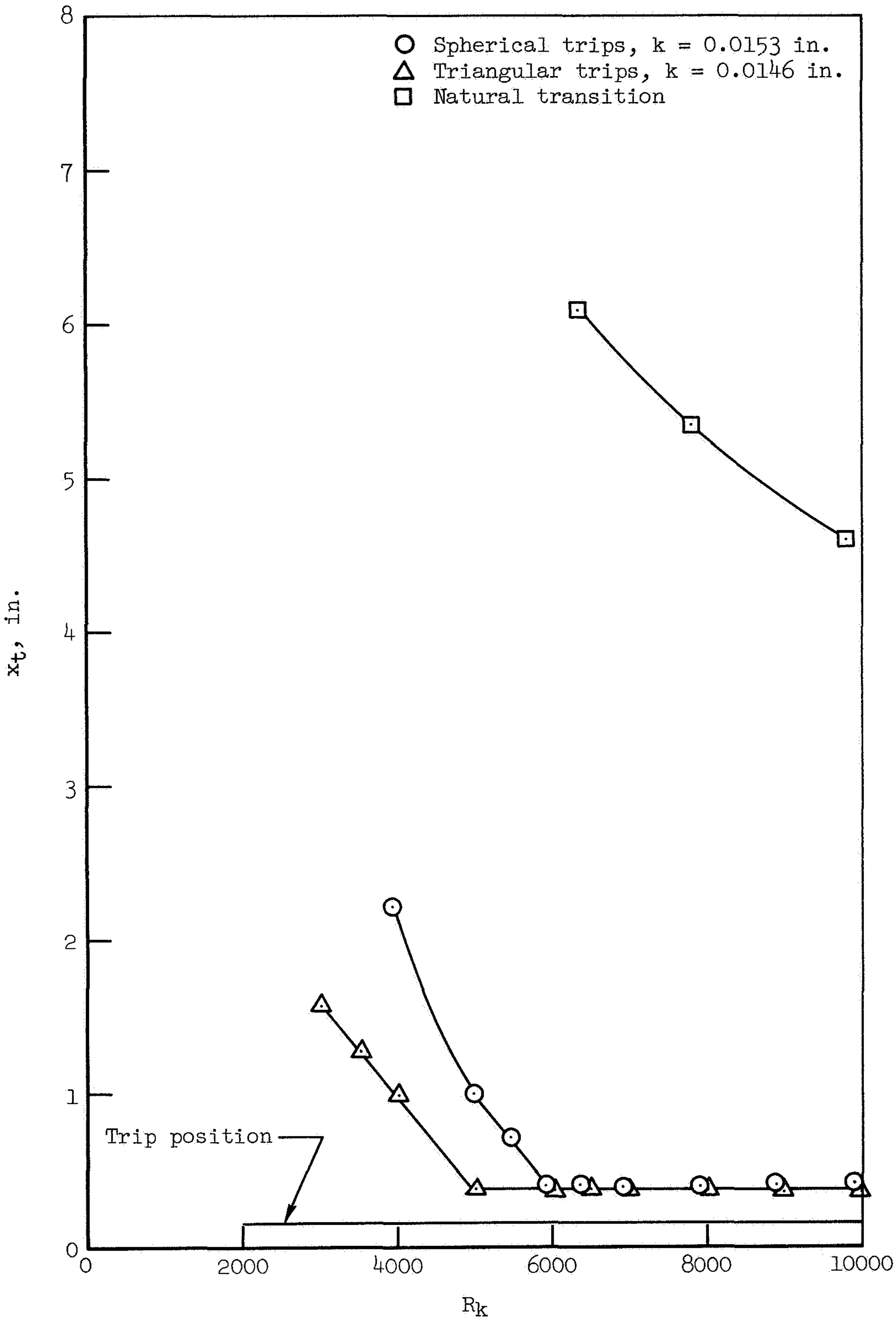
(l) M = 2.17, x = 1.00 in.

Figure 5.- Continued.



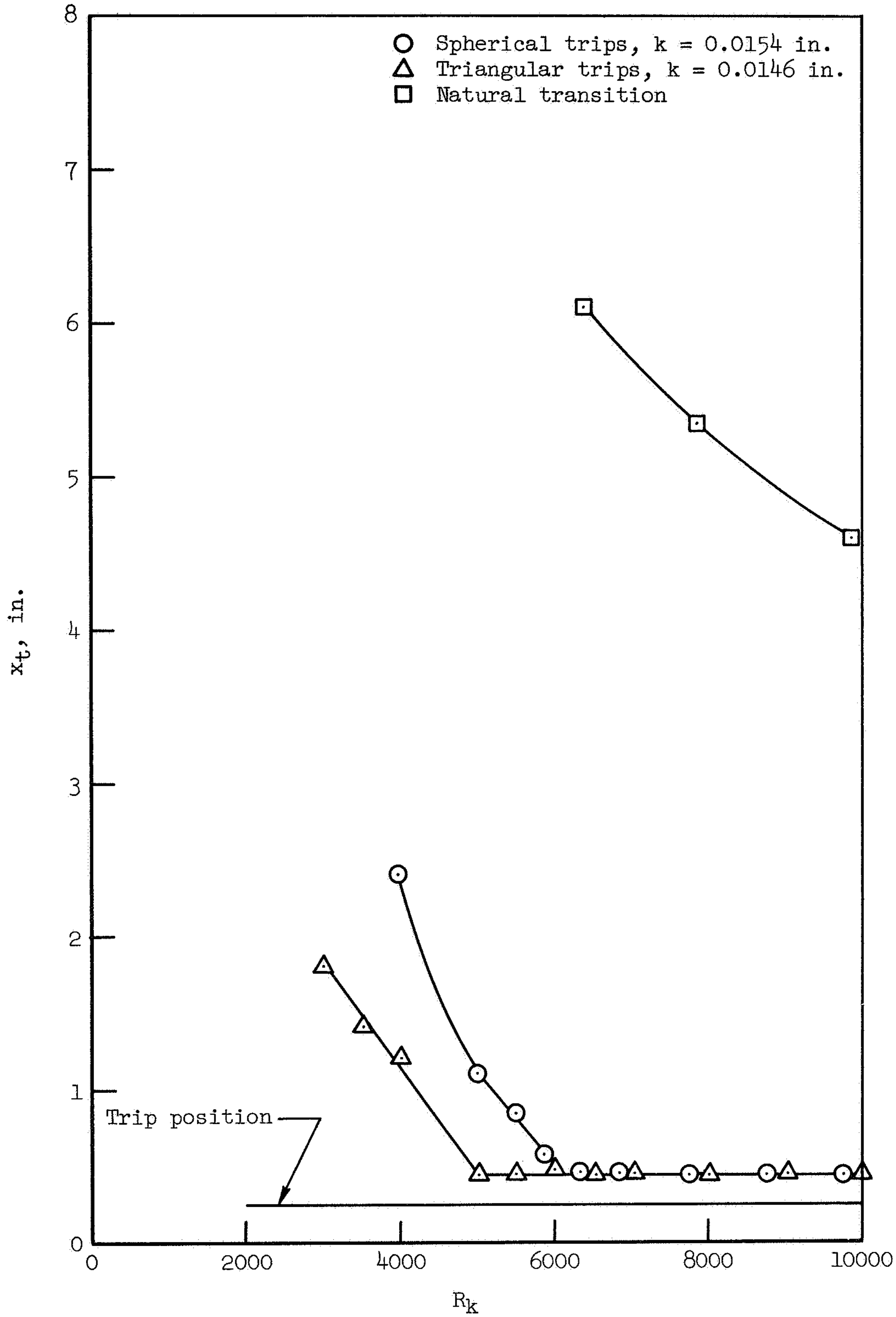
(m) M = 2.91, x = 0.08 in.

Figure 5.- Continued.



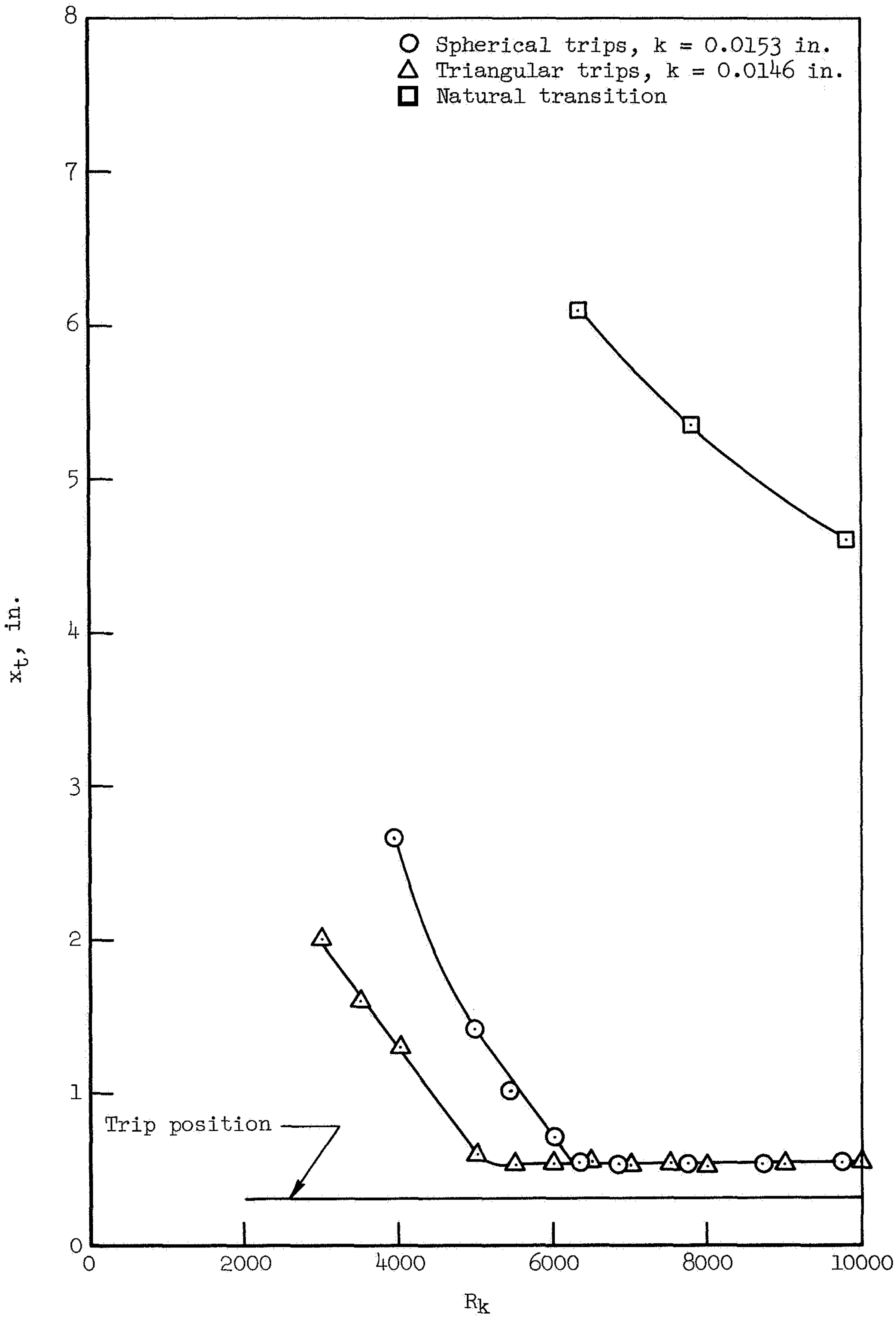
(n) M = 2.91, x = 0.16 in.

Figure 5.- Continued.



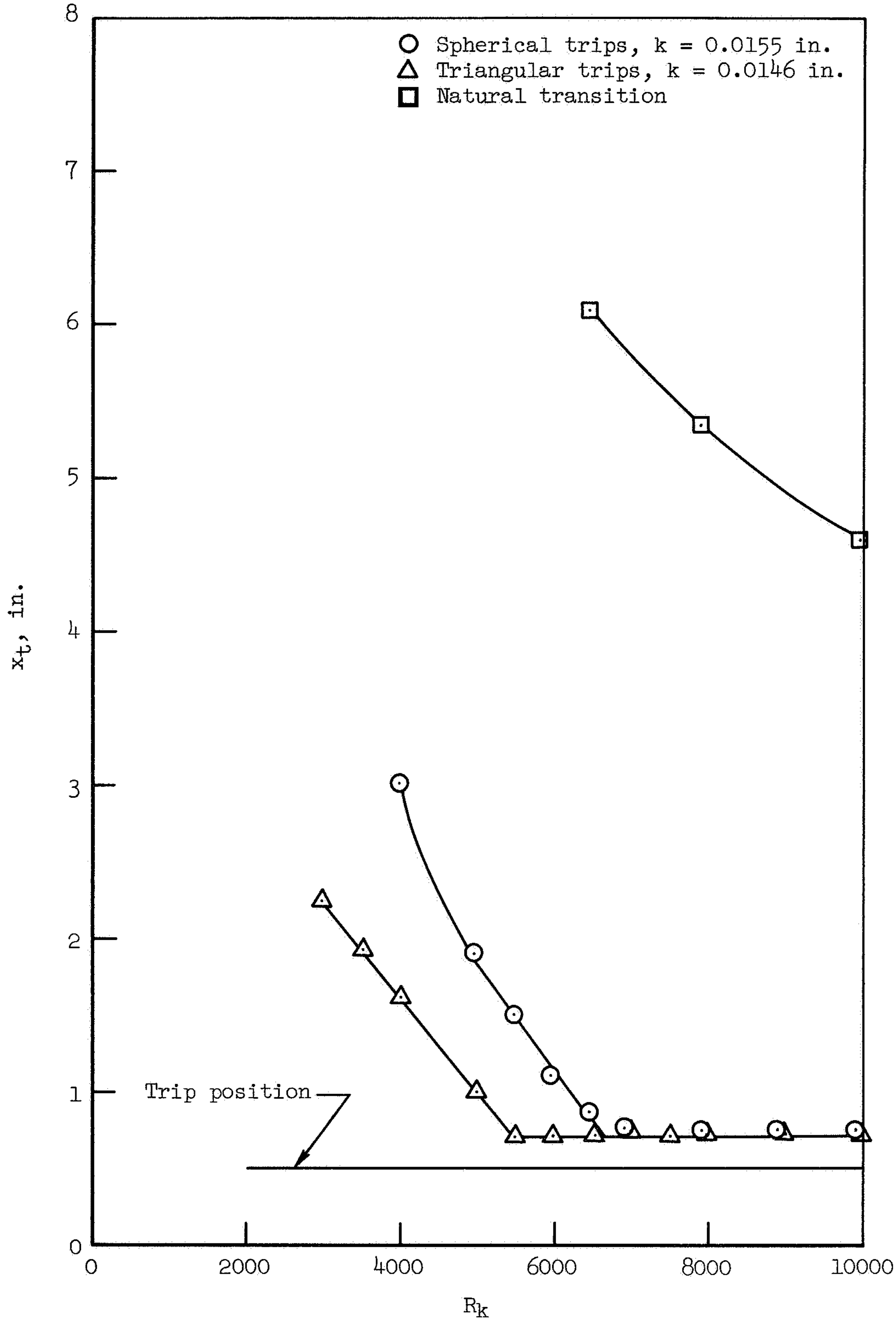
(o) M = 2.91, x = 0.25 in.

Figure 5.- Continued.



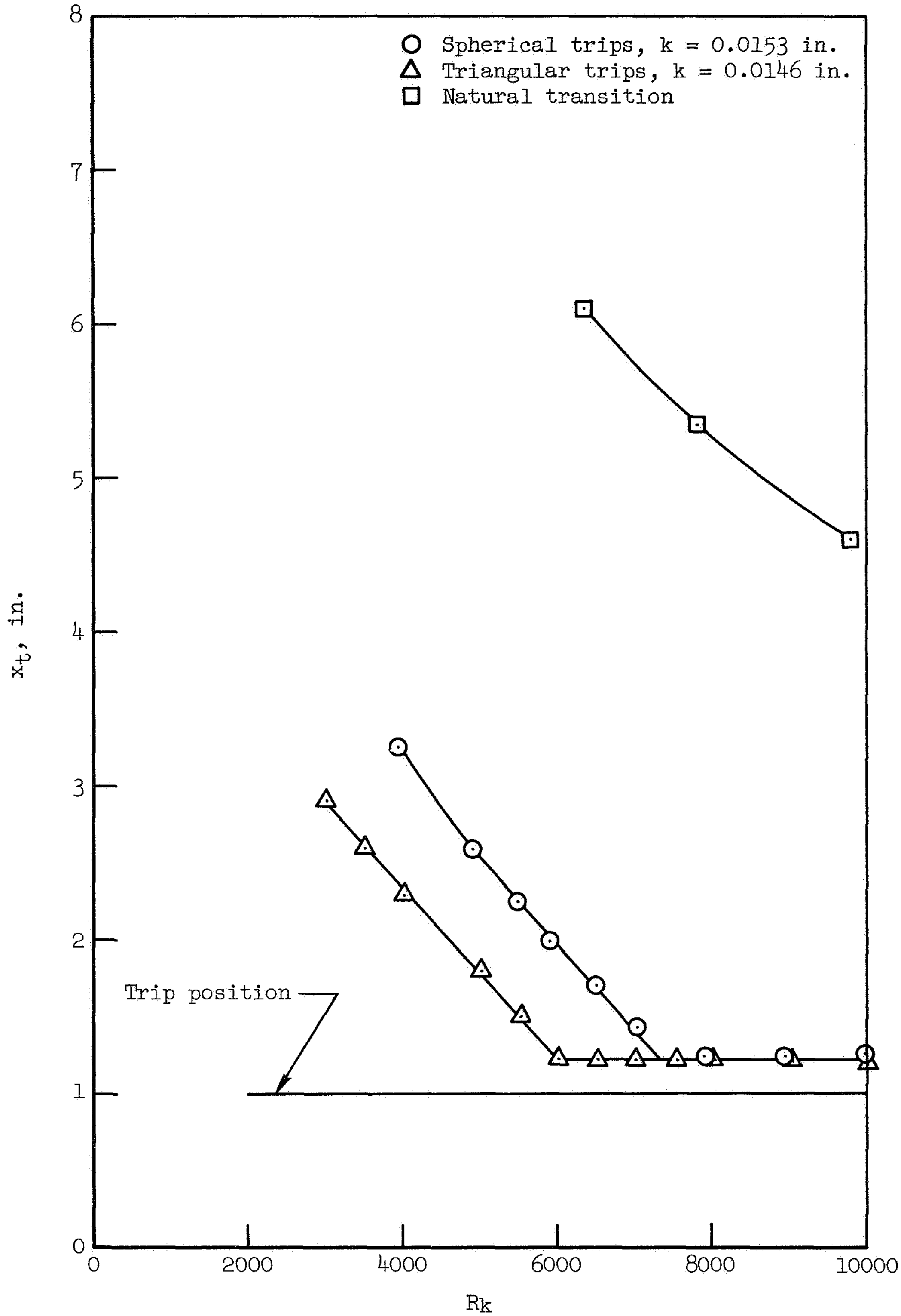
(p) M = 2.91, x = 0.32 in.

Figure 5.- Continued.



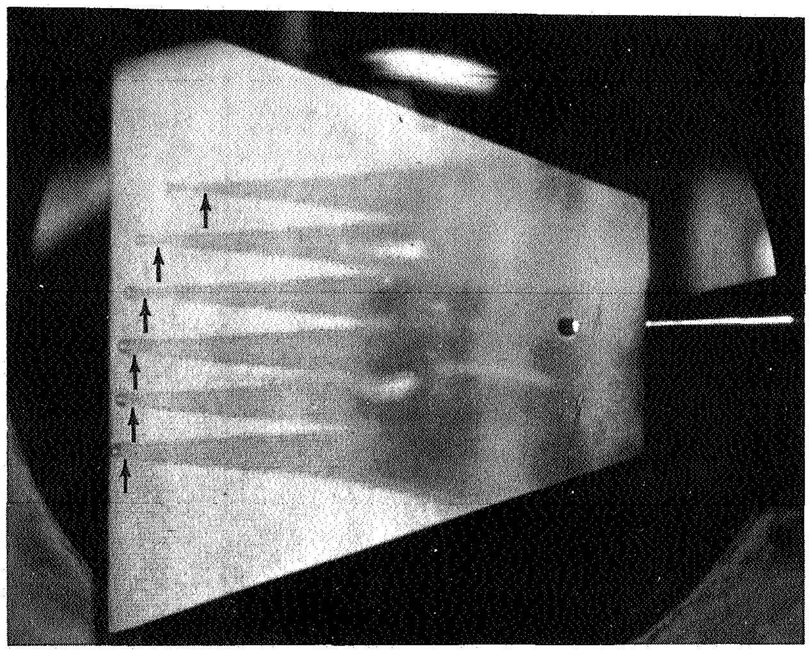
(q) M = 2.91, x = 0.50 in.

Figure 5.- Continued.

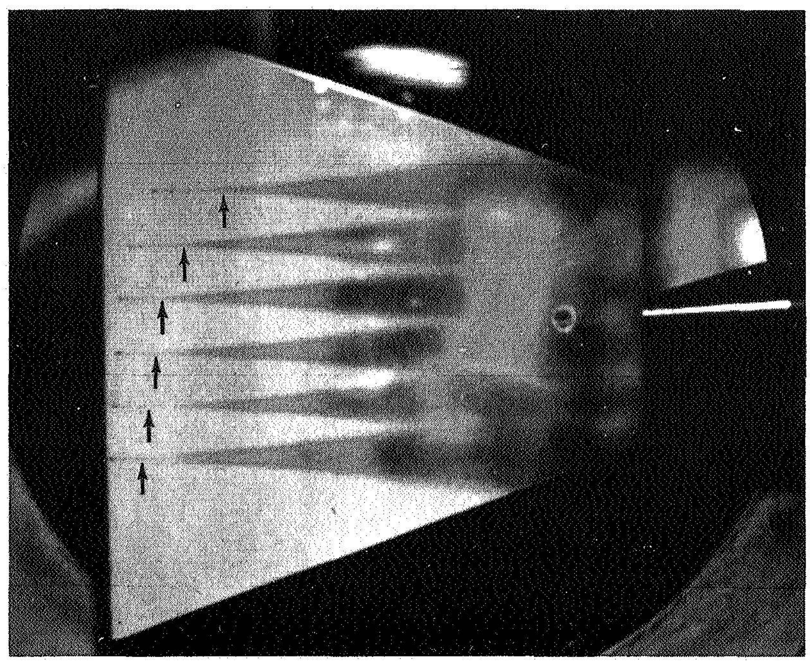


(r) M = 2.91, x = 1.00 in.

Figure 5.- Concluded.

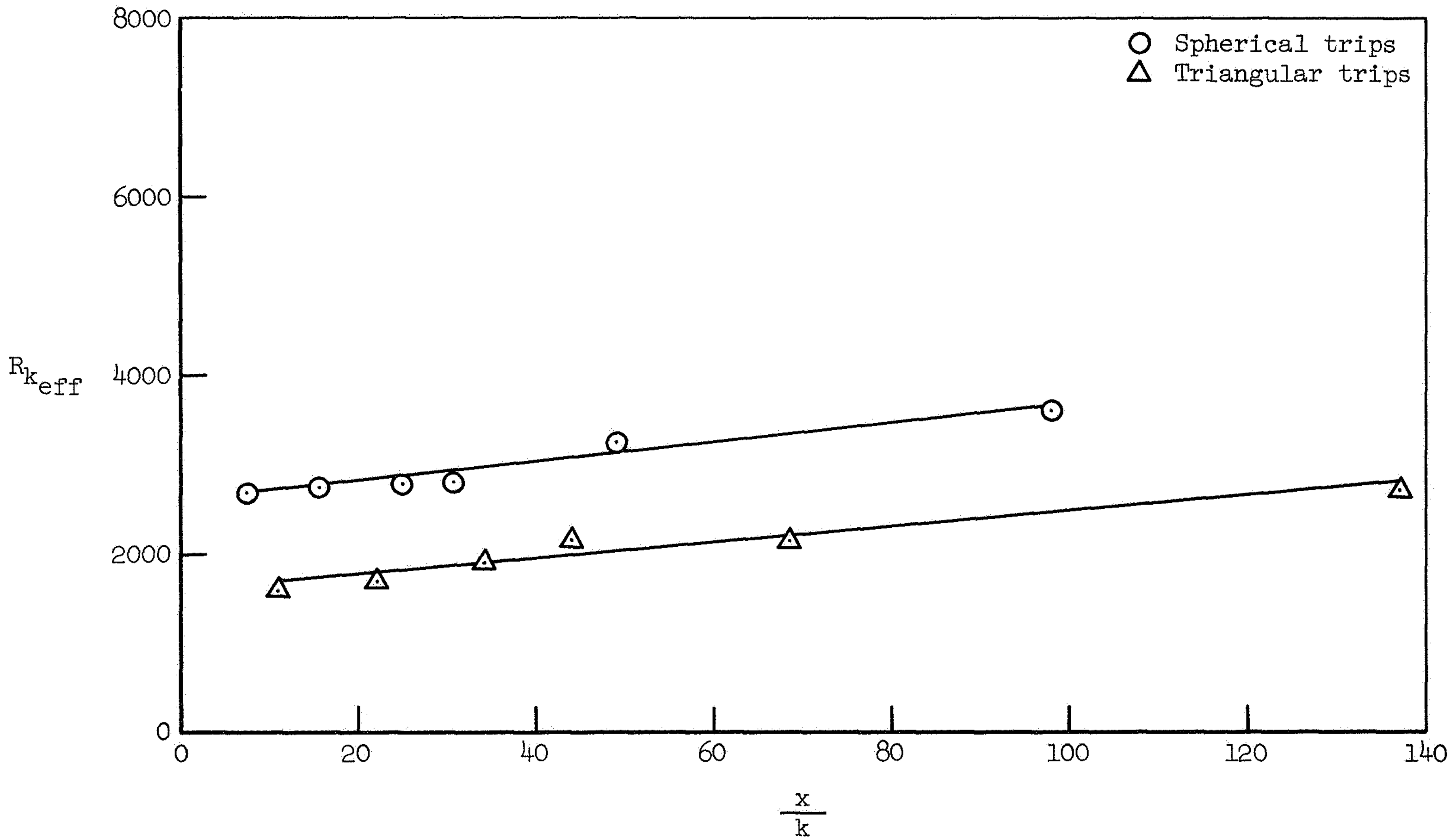


(a) Triangular trips.



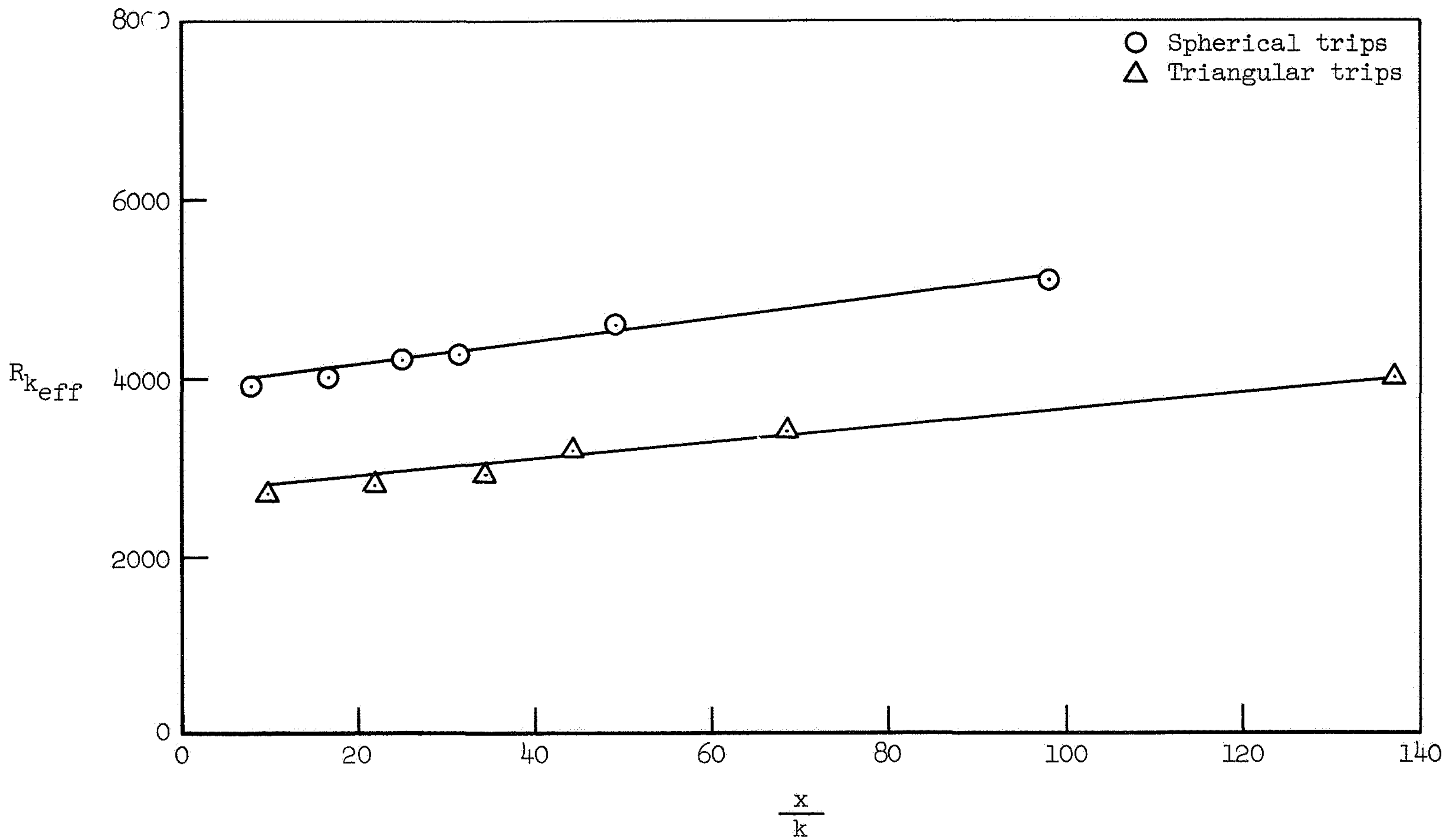
(b) Spherical trips.

Figure 6.- Comparison of spherical and triangular trips; $M = 2.91$, $R_k = 5500$. Arrows indicate start of transverse contamination as determined by cathetometer readings.



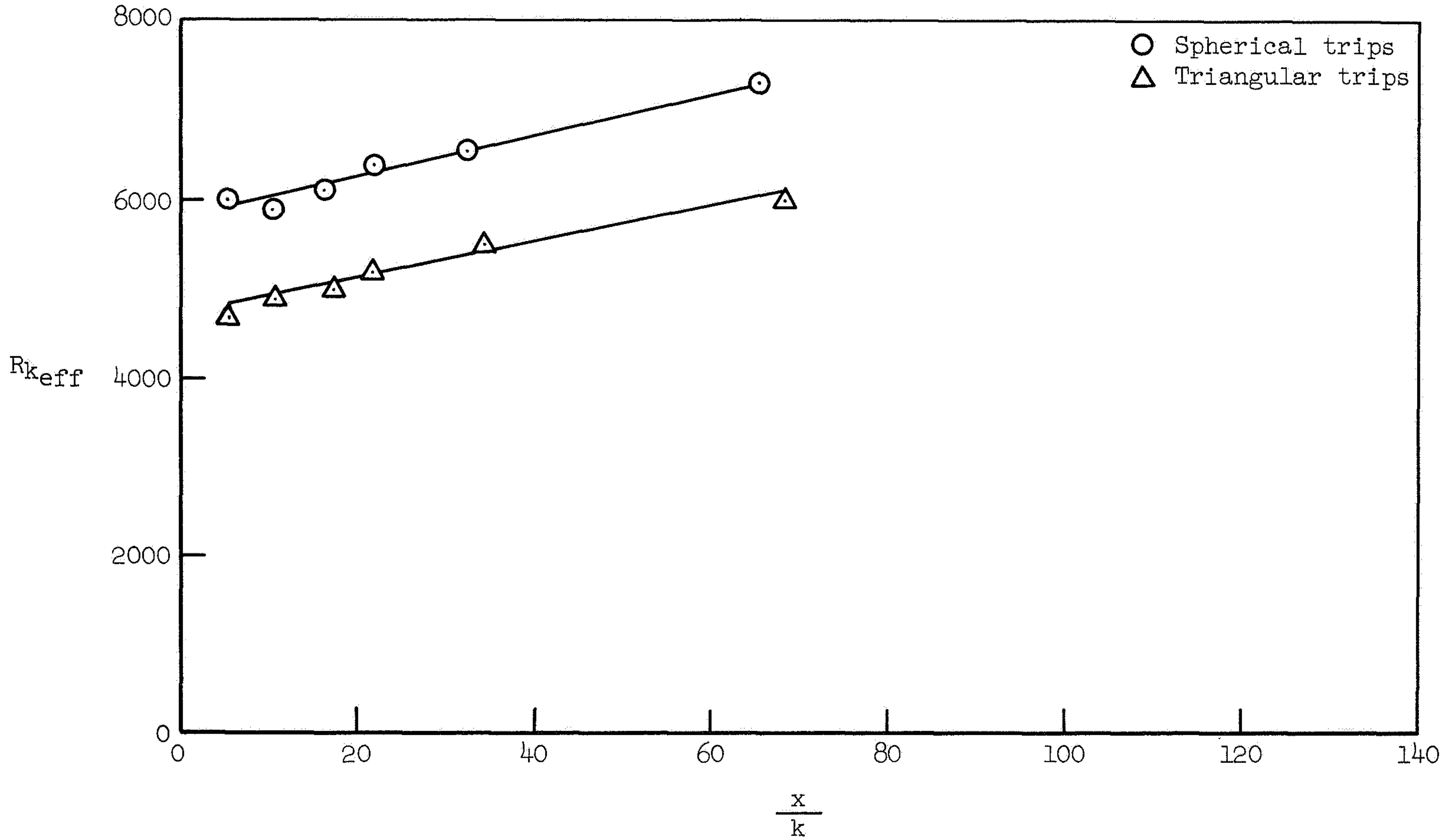
(a) M = 1.58.

Figure 7.- Effect of station to trip height ratio on effective trip Reynolds number.



(b) M = 2.17.

Figure 7.- Continued.



(c) M = 2.91.

Figure 7.- Concluded.

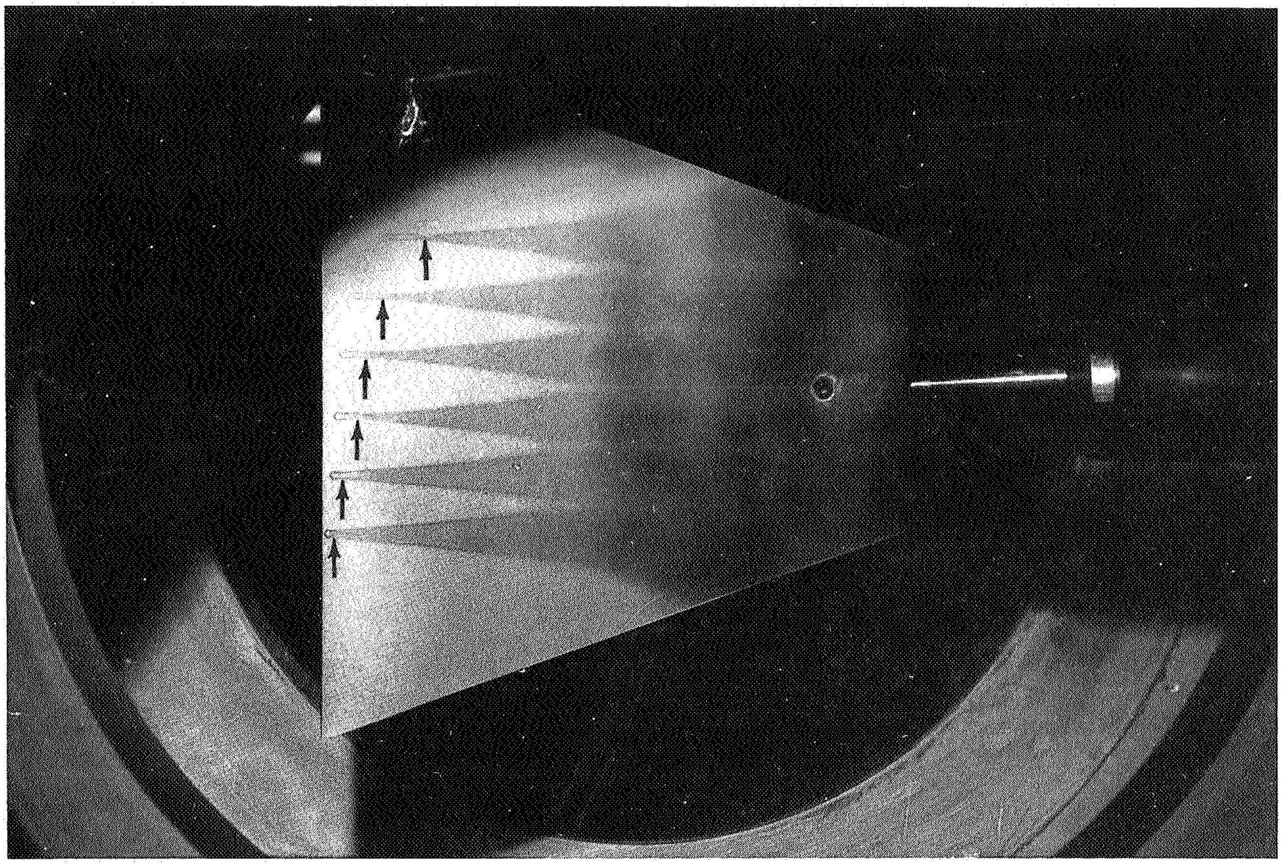
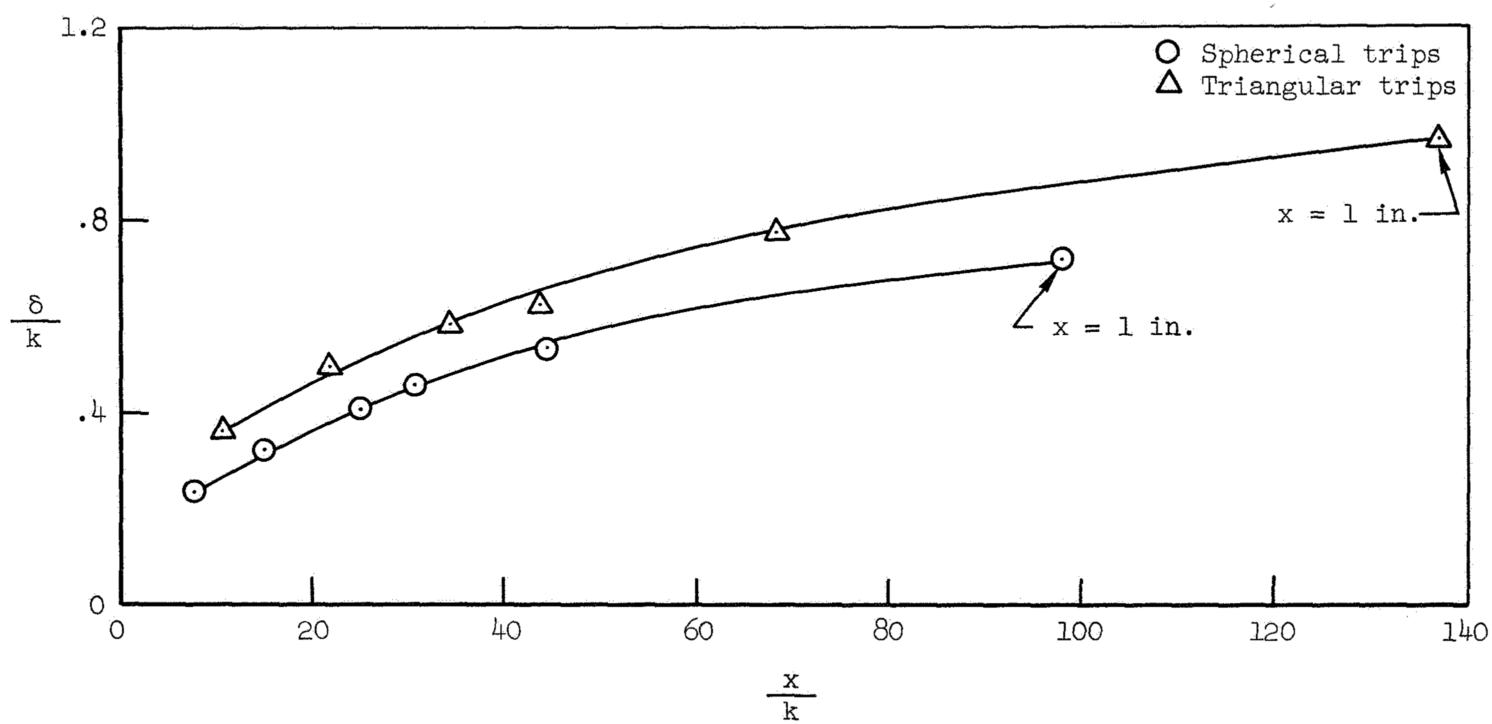
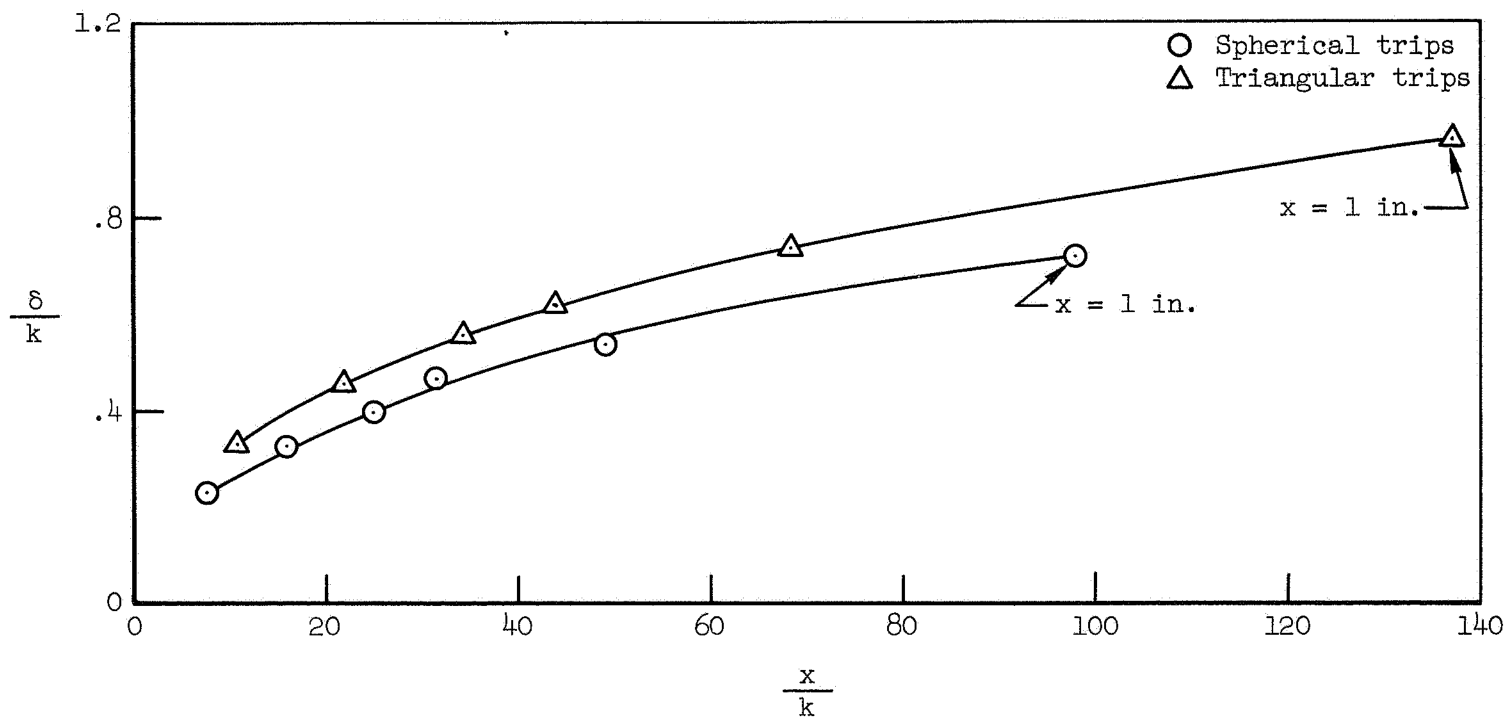


Figure 8.- Effect of station on start of transverse contamination for triangular trips; $M = 2.17$, $R_k = 2700$. Arrows indicate start as determined by cathetometer readings.



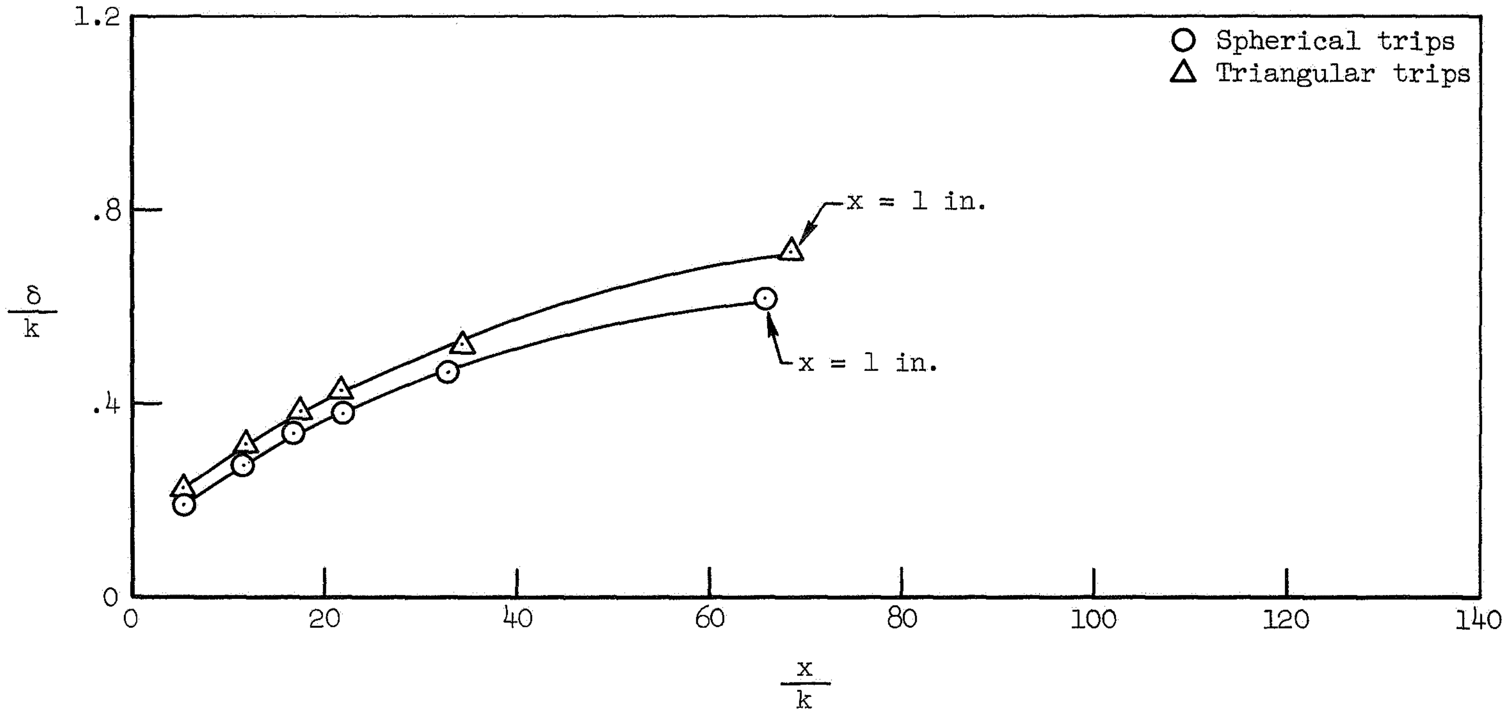
(a) M = 1.58.

Figure 9.- Effect of station to trip height ratio on boundary layer thickness to trip height ratio for effective tripping.



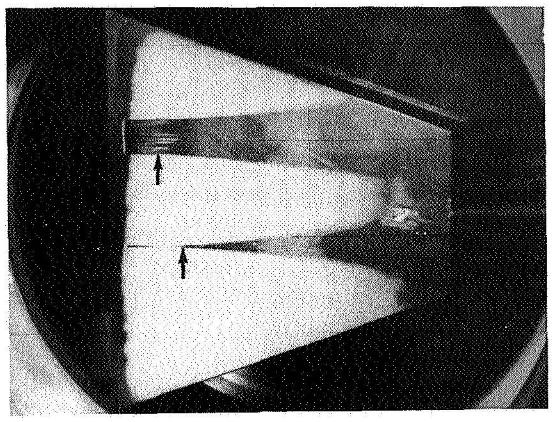
(b) M = 2.17.

Figure 9.- Continued.

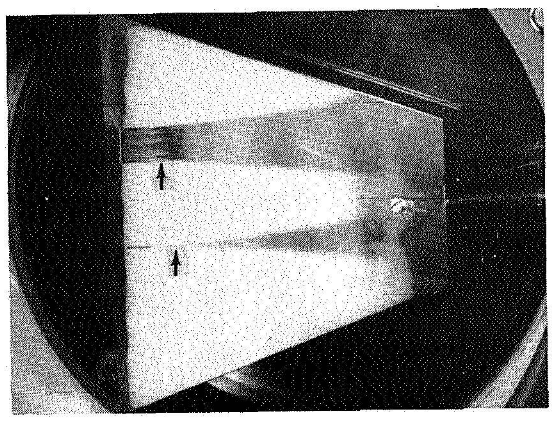


(c) M = 2.91.

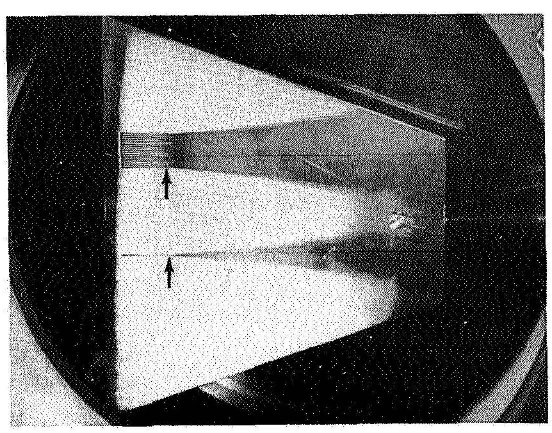
Figure 9.- Concluded.



(a) Spacing = 1 diam.



(b) Spacing = 2 diam.



(c) Spacing = 3 diam.

Figure 10.- Effect of spacing on transition due to spherical trips; $M = 2.91$; $R_k = 4800$, $x = 0.5$ in. Arrows indicate start of transverse contamination as determined by cathetometer readings.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546

OFFICIAL BUSINESS

FIRST CLASS MAIL

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS AN
SPACE ADMINISTRATION

POSTMASTER: If Undeliverable (Section 158
Postal Manual) Do Not Retur

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

— NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Notes, and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546