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TECHNICAL NOTE 4214

BOUNDARY-LAYER TRANSITION ON AN OPEN-NOSE CONE AT MACH 3.1

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SUMMARY

Comparison of transition locations for an open-nose cone, a conventional sharp cone, and a hollow cylinder showed that transition locations on the open-nose cone and the hollow cylinder were identical but differed greatly from those on the sharp cone. This is believed to be caused by the essentially two-dimensional character of the boundary layer at the leading edge of the open-nose cone.

Bluntness effects on the open-nose cone were quite similar to those observed on the hollow cylinder. Transition was displaced downstream 2.2 times the sharp-cone transition distance by blunting the tip.

INTRODUCTION

Recent theoretical considerations (ref. 1) indicate that the ratio of transition Reynolds number for a cone to that for a flat plate should be 3 if transition occurs near the minimum critical Reynolds number and 1 if transition occurs far from the minimum critical Reynolds number. These conclusions assume identical flow conditions outside the boundary layer and a minimum critical Reynolds number (based on length of run) three times as large for the cone as for the flat plate. Certain experimental evidence (ref. 2) indicates that the transition Reynolds number for a conventional 10°-included-angle cone is 2.1 times as large as for a hollow cylinder alined with the flow. This experimental fact lends qualitative support to the theoretical work, in that the transition Reynolds number for the cone is greater than that for the flat plate.

The relation between transition phenomena on a cone and on a cylinder (or flat plate) was examined by studying transition on an open-nose 10°-included-angle cone. It was hoped that such a study might indicate which geometrical factors had a predominant influence on transition location. A secondary objective was to determine the effect of bluntness of the leading edge of the open-nose cone on the transition location. Such a study has already been made for a conventional cone and a hollow cylinder (ref. 2).

SYMBOLS

b	height of bluntness (or leading-edge thickness)
C_p	pressure coefficient, $p - p_\infty/q_\infty$
p	static pressure
q	dynamic pressure
u	velocity
x	distance along model parallel to centerline
x_t	distance to transition
$x_{t,0}$	distance to transition for sharp-leading-edge condition
ν	kinematic viscosity

Subscripts:

δ	conditions at outer edge of boundary layer for a sharp body
∞	free-stream conditions

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EQUIPMENT AND PROCEDURE

The data were obtained with the identical tunnel facility used in reference 2 (1- by 1-foot test section, Mach number 3.1, unit Reynolds number range from 1 to 7×10^5 per inch, and total temperature of 80° F). The 10°-included-angle cone of reference 2 was again used but with an open nose 1 inch in diameter replacing the conventional conical tip. Its construction and dimensions are indicated in figure 1(a). Figures 1(b) and (c), which are presented for reference purposes, show the sharp 10°-included-angle cone and the hollow cylinder with which the comparative cone and cylinder data were obtained in reference 2.

The bluntness heights b used on the leading edge of the open-nose cone were 0.0005, 0.003, 0.034, and 0.098 inch, the two larger sizes having the corners rounded off to give a circular cross section to the blunt leading edge. (Ref. 2 revealed that the square corners of the larger blunted leading edges had to be rounded in order to obtain the maximum benefit of bluntness in displacing transition downstream.) A sketch of the leading edge with the various bluntnesses is shown in figure 2.

Transition positions were found from peaks in the surface temperature distributions between the laminar and turbulent regions. As in previous investigations these were found to agree closely with the mean transition location observed with schlieren photographs obtained with short-duration exposures.

RESULTS AND DISCUSSION

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Since the pressure distribution on an aerodynamic body is believed to influence the transition location, the results of pressure measurements on the open-nose cone are presented in figure 3 for a unit Reynolds number of 3.5×10^5 per inch. A strong favorable pressure gradient exists on the forward part of the model and reaches the conical pressure coefficient about 8 inches from the leading edge. Such a favorable pressure gradient would be expected to have a strong stabilizing effect on the laminar boundary layer. For comparison purposes the pressure coefficients obtained on the 10° conventional cone of reference 2 are indicated, except for the high point at $x = 20$ inches, which has recently been found to be in error. By comparison with the open-nose cone the pressure distribution on the conventional cone is relatively flat, and little effect on the transition location would be expected.

Transition locations obtained from peak surface temperatures are shown in figure 4 for the 10° open-nose cone. The corresponding results from reference 2 for the 10° conventional cone and the hollow cylinder are also shown for comparison. All results in figure 4 are for sharp-leading-edge and sharp-tip configurations.

Transition locations for the open-nose cone and the hollow cylinder are almost identical throughout the unit Reynolds number range (fig. 4). The favorable pressure gradient on the open-nose cone appears to have very little if any effect in delaying transition. The principal result seems to be that the two-dimensional character of the boundary layer at the open nose controls the location of transition and causes it to occur in the same position as for the hollow cylinder. This result is quite plausible when one considers that the minimum critical Reynolds number for stability occurs at a distance of less than 0.01 inch from the leading edge, assuming a critical Reynolds number of 1000 for Mach 3.1 (ref. 3). Hence, two-dimensional stability considerations may be the controlling factor in establishing the transition from laminar to turbulent flow.

The flow conditions at the open nose were always such that the shock was swallowed internally, and for the sharp configuration the shock was attached to the leading edge. The results presented in figure 4 would probably depend to a certain extent on the opening size; that is, smaller hole sizes should produce transition locations more nearly equal to those on the sharp cone.

The effect of leading-edge bluntness on the transition location for the open-nose cone is indicated in figure 5. Transition moves downstream progressively as the leading edge is blunted to $b = 0.003$ and 0.034 inch. Further blunting to 0.098 inch does not appear to produce any further significant downstream displacement of the transition point. At this point transition is displaced downstream 2.2 times the sharp-leading-edge transition distance. Calculations using equation (12) of reference 4, assuming that the laminar boundary layer is two-dimensional, indicate that a bluntness of 0.08 inch is required to immerse the entire boundary layer inside the low-speed part of the shock layer. Apparently it is not necessary to use the full bluntness suggested in reference 4 to obtain the maximum transition delay. The limit in downstream movement of the transition point for the 0.034- and 0.098-inch bluntnesses at unit Reynolds numbers less than 10^5 per inch is believed to be caused by the reflection of the leading-edge shock wave from the tunnel walls.

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Figure 6 shows the bluntness results of figure 5 plotted as bluntness Reynolds number against transition-distance ratio. This is the same type of plot used in reference 2 to correlate bluntness effects on a hollow cylinder and a conventional cone. The bluntness Reynolds number $u_\delta b/\nu_\delta$ is based on sharp-body inviscid-flow conditions and the actual bluntness height (leading-edge thickness at the tip). The transition-distance ratio $x_t/x_{t,0}$ is the distance to transition for the blunt configuration divided by the distance for the sharp configuration (taken to be the 0.0005-in. leading edge for the open-nose cone). The unit Reynolds number u_δ/ν_δ was always taken to be the same for the sharp as for the blunted leading edge in obtaining $x_t/x_{t,0}$.

In figure 6 the transition movement with increasing bluntness parallels that for the blunt cylinder but at slightly higher bluntness Reynolds numbers. This slight increase in bluntness Reynolds number is probably caused by a thinning of the inviscid shock-produced layer (ref. 4) as the shock layer passes over an increasing cone perimeter. The maximum transition-distance ratio for the open-nose cone is close to the theoretical value of 2.13 obtained using figure 2(b) of reference 4. This theoretical value considers only the effect of the unit Reynolds number reduction at the outer edge of the boundary layer. It also assumes a constant transition Reynolds number independent of Mach number and unit Reynolds number changes. That these two factors might cause a small change in the theoretical value is discussed in reference 2. With respect to bluntness, no similarity in transition location between the open-nose cone and the conventional cone was observed.

SUMMARY OF RESULTS

From a comparison of transition locations on an open-nose cone, a sharp cone, and a hollow cylinder, the following results were obtained:

1. Transition locations for a sharp open-nose cone occurred at the same position as for a sharp hollow cylinder throughout the Reynolds number range. There was no similarity between the transition locations on the open-nose cone and those on the sharp-tipped cone at any Reynolds number.

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2. Blunting an open-nose cone produced transition delays about 2.2 times the sharp open-nose-cone transition distance. These delays are similar in magnitude to those observed on a hollow-cylinder model and similar to those predicted by theory.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, November 15, 1957

REFERENCES

1. Tetervin, Neal: Remarks Concerning Transition Reynolds Numbers on Cones and Flat Plates. Jour. Aero. Sci., vol. 24, no. 7, July 1957, pp. 545-546.

2. Brinich, Paul F., and Sands, Norman: Effect of Bluntness on Transition for a Cone and a Hollow Cylinder at Mach 3.1. NACA TN 3979, 1957.

3. Van Driest, E. R.: Calculation of the Stability of the Laminar Boundary Layer in a Compressible Fluid on a Flat Plate with Heat Transfer. Jour. Aero. Sci., vol. 19, no. 12, Dec. 1952, pp. 801-812.

4. Moeckel, W. E.: Some Effects of Bluntness on Boundary-Layer Transition and Heat Transfer at Supersonic Speeds. NACA Rep. 1312, 1957. (Supersedes NACA TN 3653.)

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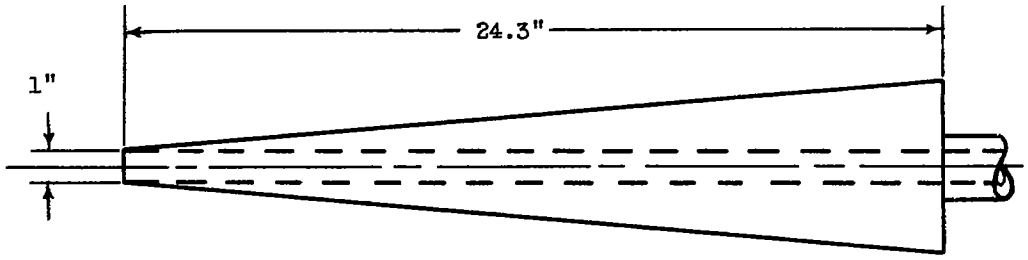
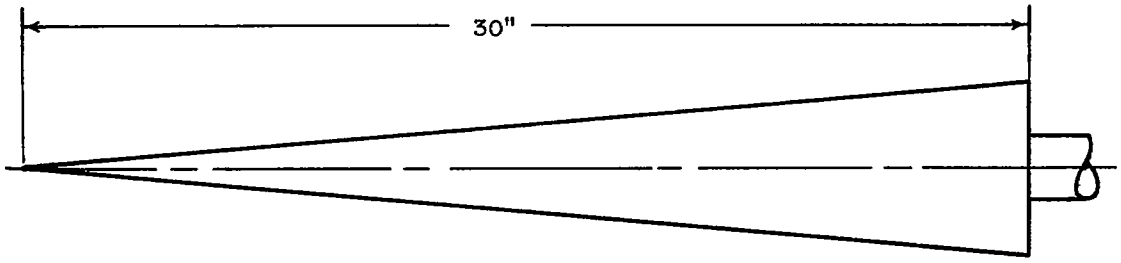
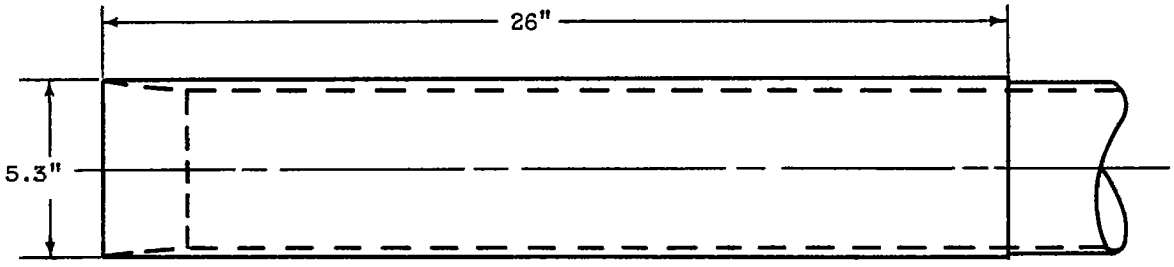


(a) Open-nose cone (10° included angle).



(b) Sharp-tip cone (10° included angle).



(c) Hollow cylinder.

Figure 1. Experimental models.

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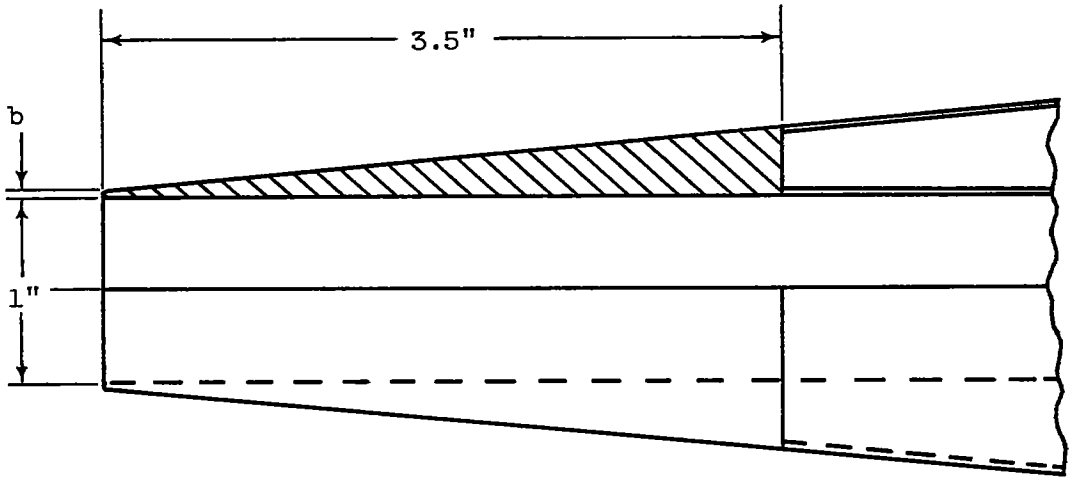

Figure 2. - Open-nose-cone detail. Bluntness height, b, of 0.0005, 0.003, 0.034, and 0.098 inch.

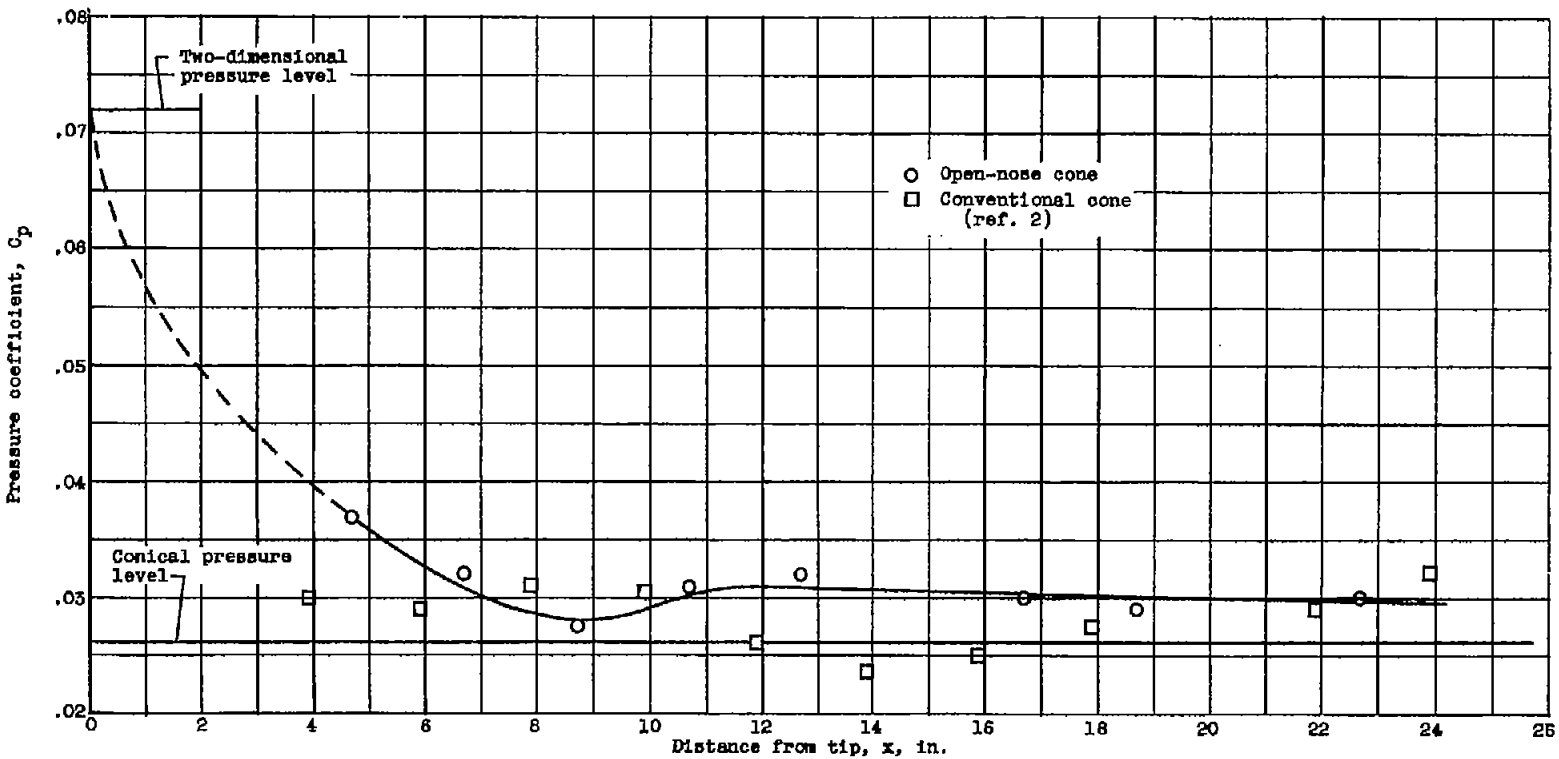

Figure 3. - Pressure distribution on open-nose and conventional cones (10° included angle). Unit Reynolds number, u_δ/ν_δ, 3.5×10^5 per inch.

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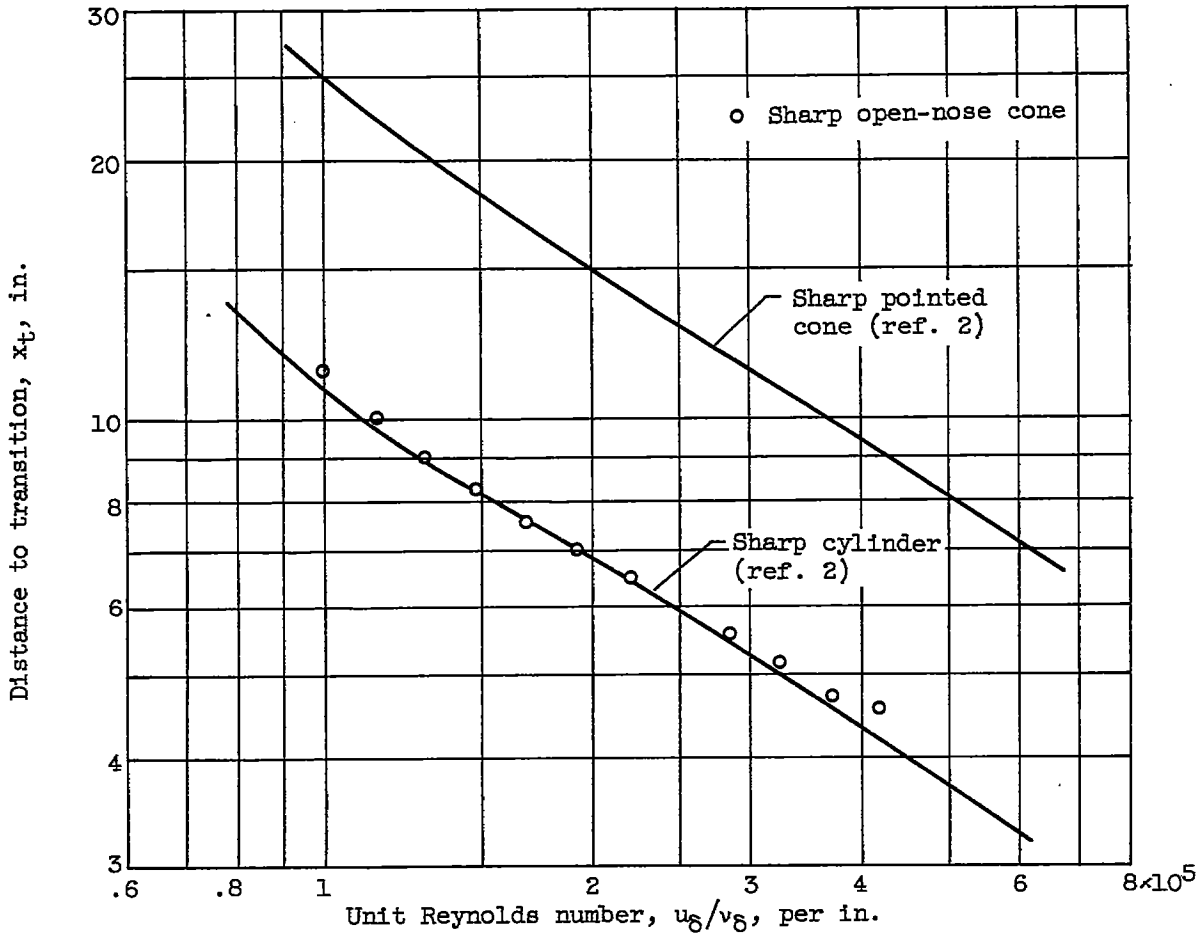

Figure 4. - Transition locations on open-nose cone, sharp cone, and sharp hollow cylinder.

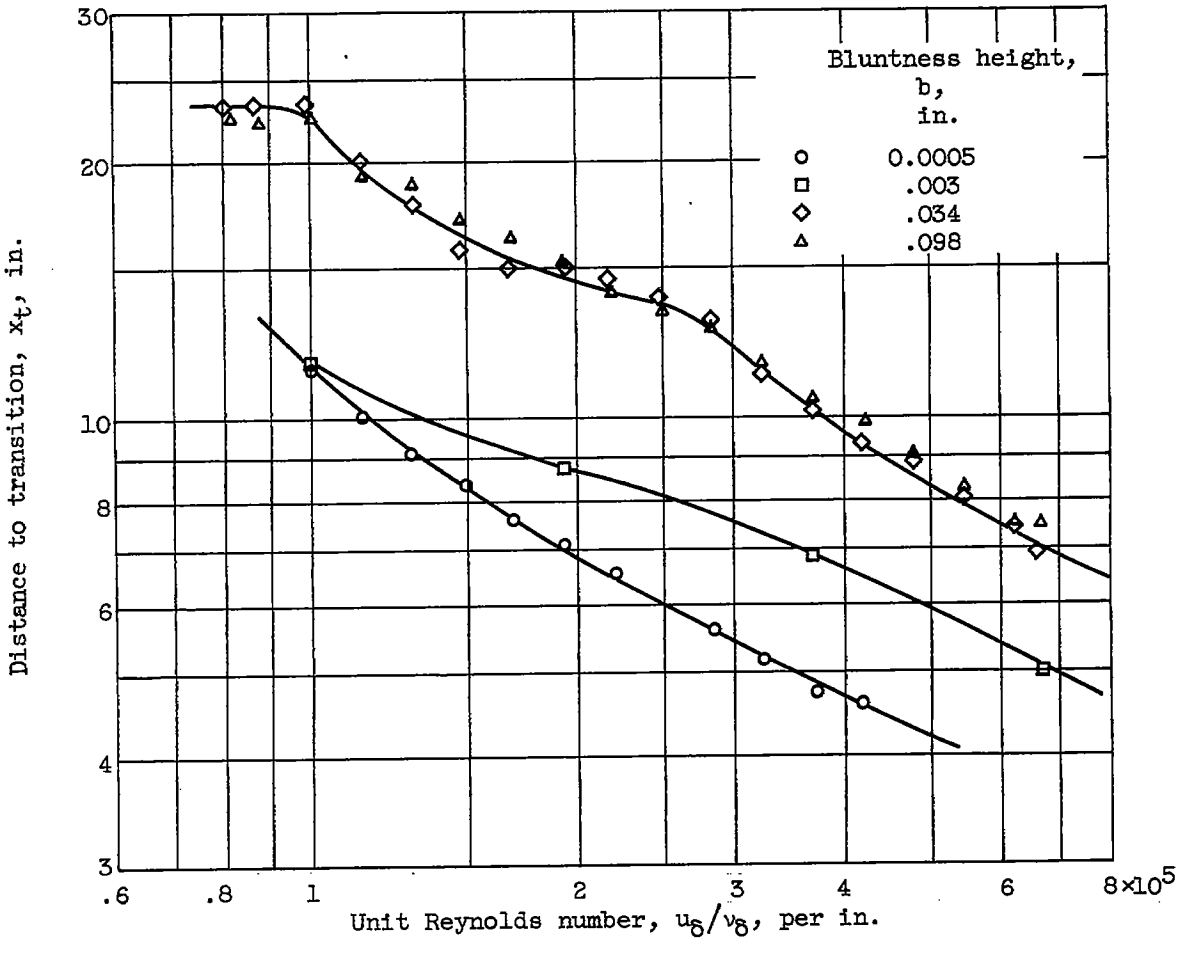

Figure 5. - Transition locations on a blunted open-nose cone.

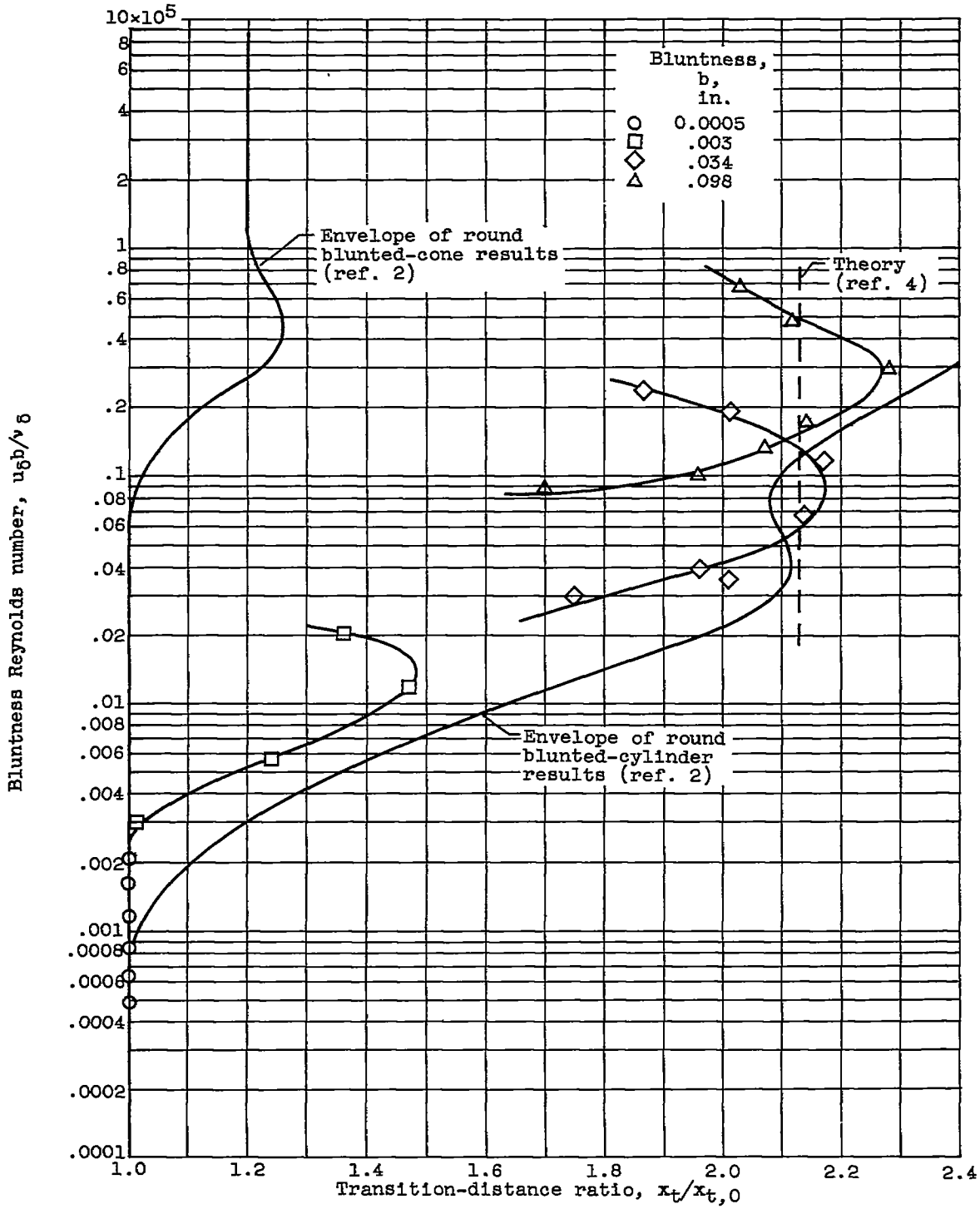

Figure 6. - Effect of bluntness Reynolds number on transition location for blunt open-nose cone.

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