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DEPARTMENT OF MECHANICAL ENGINEERING AND MECHANICS
SCHOOL OF ENGINEERING
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA

SCALE MODEL STUDIES FOR IMPROVEMENT OF FLOW PATTERNS OF A LOW-SPEED TUNNEL

By

P.S. Barna, Principal Investigator

Progress Report
For the period August 1, 1980 - February 28, 1981

Prepared for the
National Aeronautics and Space Administration
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Hampton, Virginia

Under
Research Grant NSG 1563
Richard J. Margason, Technical Monitor
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Submitted by the
Old Dominion University Research Foundation
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P.S. Barna*

INTRODUCTION

This report summarizes work performed under NASA grant NSG 1563 during the period from August 1, 1980 to February 28, 1981. Significant results were achieved in the following areas: (1) investigation of flow along the nacelle with and without the presence of an orifice plate, (2) studies of various windmills and their effects on the downstream flow pattern, (3) efforts toward construction of the model tunnel, and (4) investigation of velocity traverses at relevant sections of the completed model tunnel.

DETAILS OF WORK

Investigation Along Nacelle

Earlier tests with the empty tunnel indicated the flow distribution could be influenced by the insertion of an orifice into the airstream. It was found that the flow became more uniform in transit through the orifice when compared with the upstream flow and that it also remained more uniform immediately downstream from the orifice. The beneficial effects, however, were only local: no improvement could be found further downstream. These tests were subsequently repeated with the nacelle in position but without the fan. Qualitatively the results were found to be about the same as before the nacelle was inserted.

Figures 1 and 2 show the flow at a distance $x/R = 0.25$, and the improvement can be observed when comparing the velocity traverses. Figure 3 shows the decreased effect of the orifice at $x/R = 0.45$.

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The orifice employed had an opening of 48.3 cm (19 in.) in the section where the diameter of the tunnel was 50.8 cm (20 in., orifice-to-tunnel diameter ratio = 0.949, tunnel or fan radius R = 25.4 cm, 10 in.).

Investigation of Windmills

Although windmills have been employed in wind tunnels downstream from the fan to improve the flow distribution in the diffuser, there appear to be no data in the literature on the results obtained with windmills in wind tunnels. Moreover, there are also no results available concerning the spreading of the airstream in transit through a windmill.

The Theory of Windmills is generally based on the simple actuator disc concept and predicts an increase in the diameter d_2 of the downstream flow as compared to the upstream flow d_1. It was thought that, for a specified pressure decrease across the windmill "disc," the diameter ratio d_2/d_1 could be established and thus the spreading could be calculated. Figure 4 shows plots of such results calculated by the actuator disc theory.

Experiments were performed to check this theory and to establish the rate of spreading (d_2/d_1) with distance x from the plane of the windmill. These experiments proved time consuming and did not produce the rate of spreading with distance. Efforts were expanded over several months to find the proper device for braking the speed of the free-wheeling propellers (employed as substitute windmills) which were placed into the 3 x 4 ft low-speed wind tunnel at the Old Dominion University Engineering Labs. Small electric generators of various outputs proved unsatisfactory, but finally an electromagnetic brake was installed which allowed the propeller's rotation to be controlled and the torque to be measured (see fig. 5).

The experiments proved that the windmill retarded the flow velocity inside an area of size approximately equal to the size of the "disc" diameter, that is, inside the circle inscribed by the tip of the propeller, while the main stream passed over the blades seemingly unrestricted and without showing an increase in diameter to any appreciable extent. Figure 6 shows sample flow distributions with a 3-bladed propeller of

61-cm (24-in.) diameter at various distances measured downstream from the plane of rotation. These results show that by varying a torque the flow across a windmill can be effectively redistributed — an effect, that could be gainfully employed in situations where the main flow into a diffuser is concentrated near the center, similar to that experienced in the V/STOL diffuser downstream from the fan.

Construction of the Model Tunnel

Construction of the model tunnel was completed by the end of January 1981. The tunnel circuit was mounted on 4 separate tables, each 1.8-m (6-ft) long, 0.6-m (2-ft) wide and 0.9-m (3-ft) high. These tables are easy to handle and can be removed from the laboratory without disturbing the various components of the tunnel. The components were bolted to the platform with suitable brackets.

The original idea of driving the fan with a 1.12×10^4 W (15-HP) continuously variable speed motor had to be shelved, as the required voltage to the motor-set was not readily available. A four-speed motor usually driving a large centrifugal fan, was employed instead. When the tunnel was first run, the long shaft driving the fan showed resonance at the second speed of the motor. Steps are being taken to eliminate this resonance. However, the tunnel as a unit works to expectations, and the actual air speed in the closed test section exceeded the design speed of 75 m/s (220 ft/s). The model tunnel is one twenty-fourth the scale size of the large prototype. A photograph of the model tunnel is shown in figure 7.

Velocity Traverses Obtained on the Model Tunnel

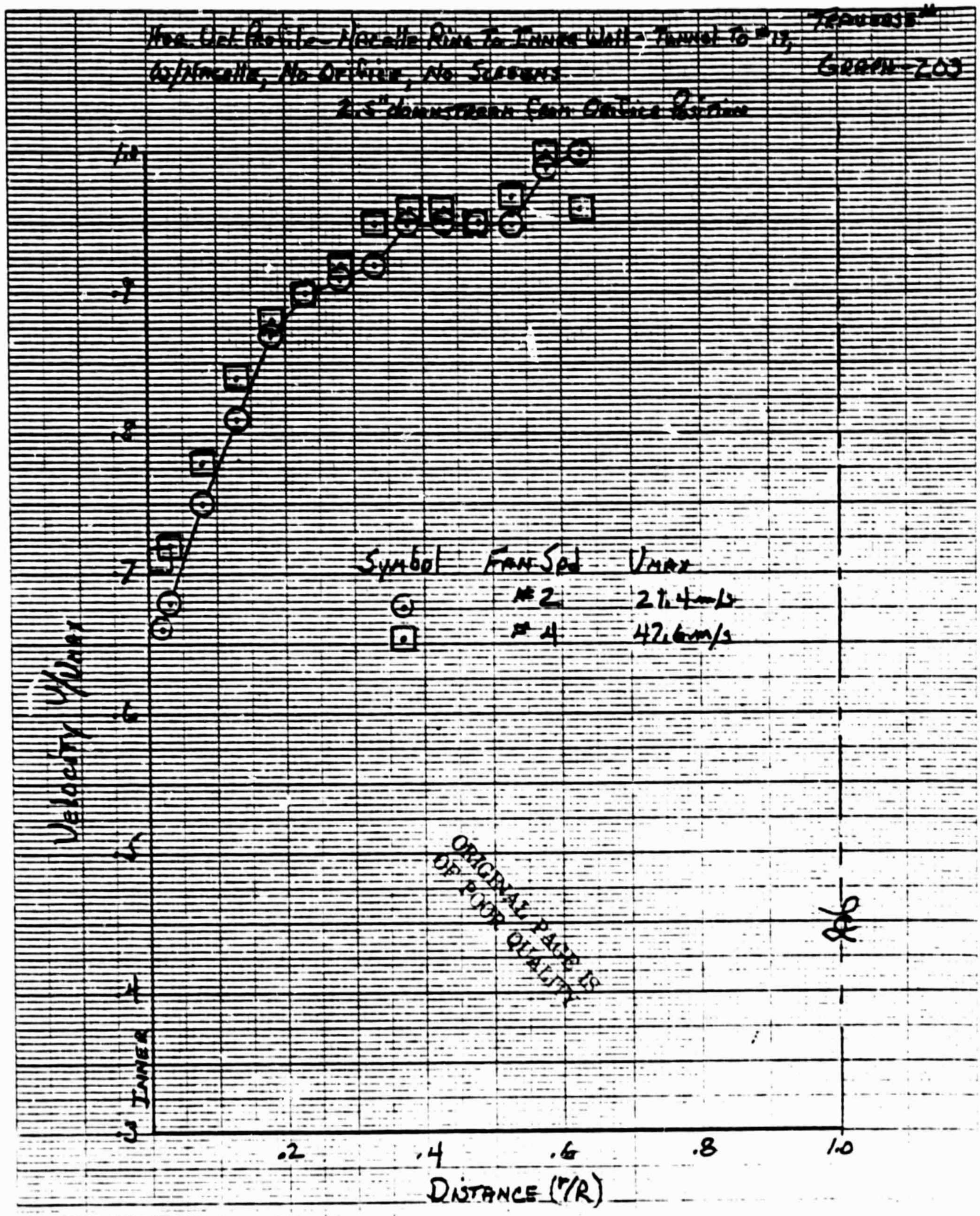
Most recently velocity traverses (as samples) were obtained at traverse stations (T.S.) 21 (inlet to the test section), 1, 5, 8A, 9/B, 15, 16 and 18, as shown in figure 8. These traverses show a similar pattern to those obtained with the prototype V/STOL tunnel. These patterns therefore do not represent much information that is new, with the exception of the vertical traverses obtained at stations 9/B and 10/A. (Figure 9 is attached for convenience.

These traverses indicate that the velocity distribution may be considered worse in the vertical than in the horizontal plane. This is due to the geometry of the second diffuser, which has parallel side walls, while the floor and ceiling are inclined to promote diffusion.

It may also be of interest to note that, at T.S. 16, the velocity distribution was less "peaky" in the model tunnel near the center, although separation of flow from the outer wall seemed almost complete.

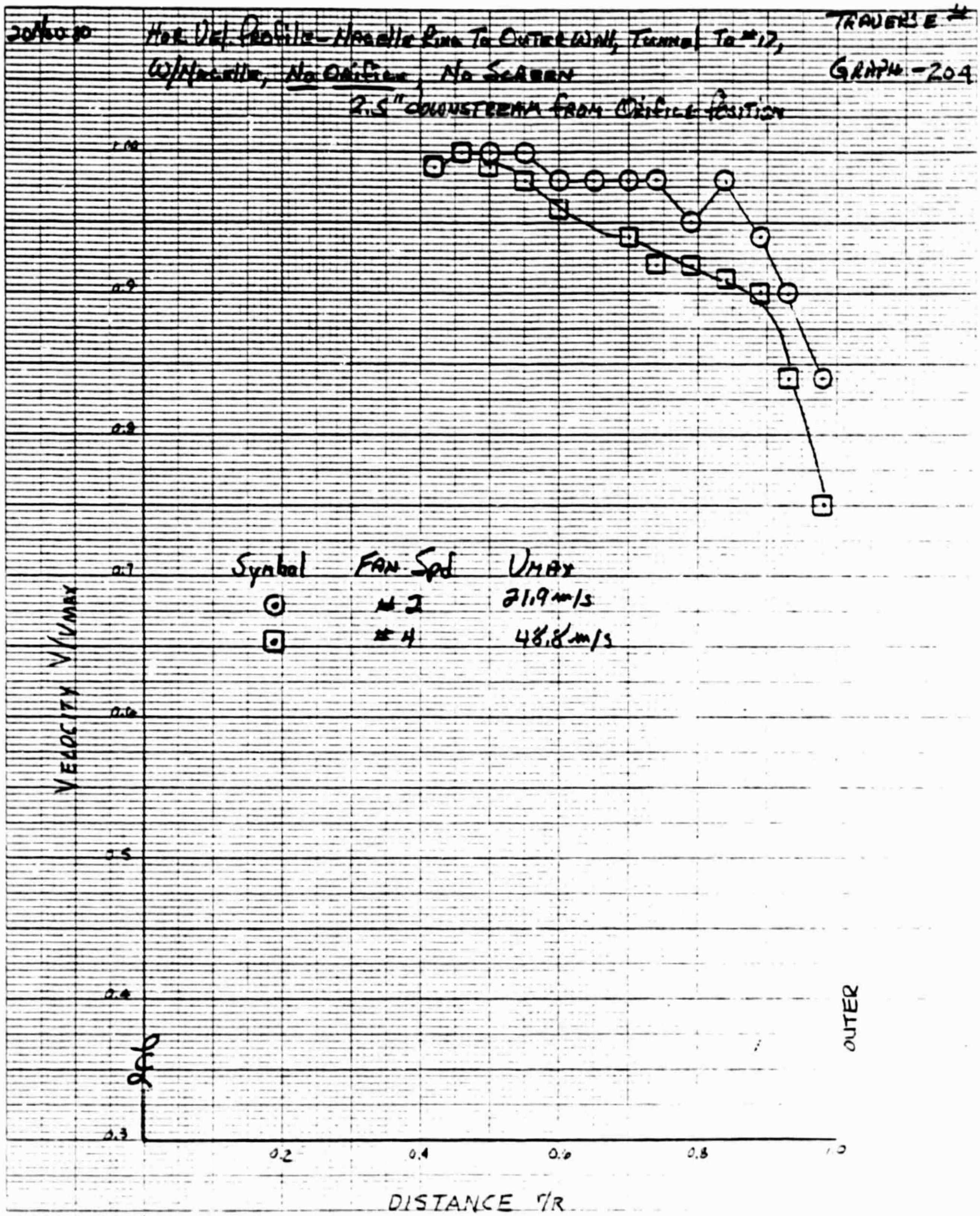
FUTURE ACTIVITY

Intensive studies of the model tunnel are planned. Various ideas for improving the flow will be tested. A final report of these efforts will be presented.



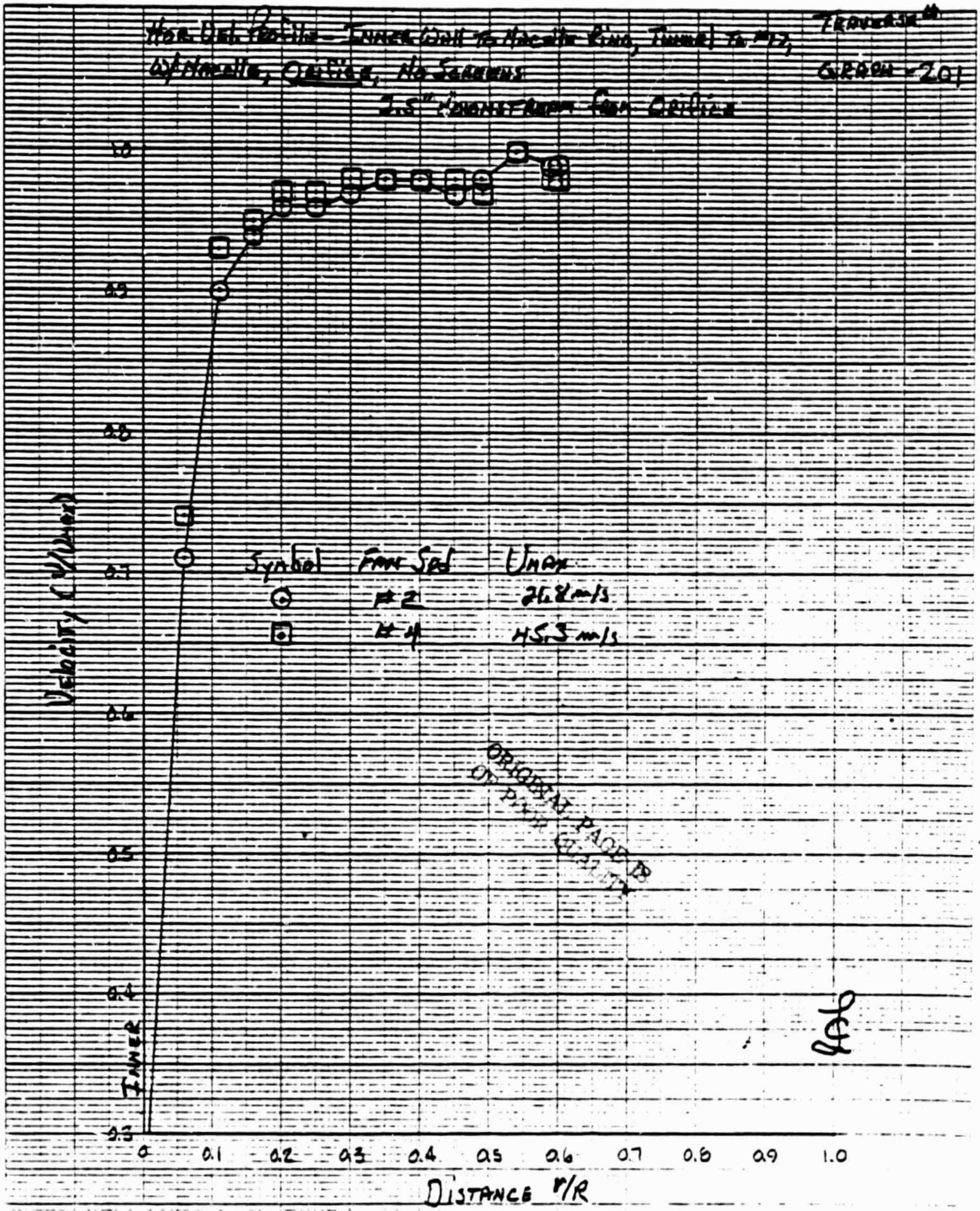
(a) Between inner wall and nacelle.

Figure 1. Flow distribution over nacelle at a location 6.35-cm (2.5-in.) downstream from T.S. 13 without the presence of the orifice [R = 25.4 cm (10 in.)].



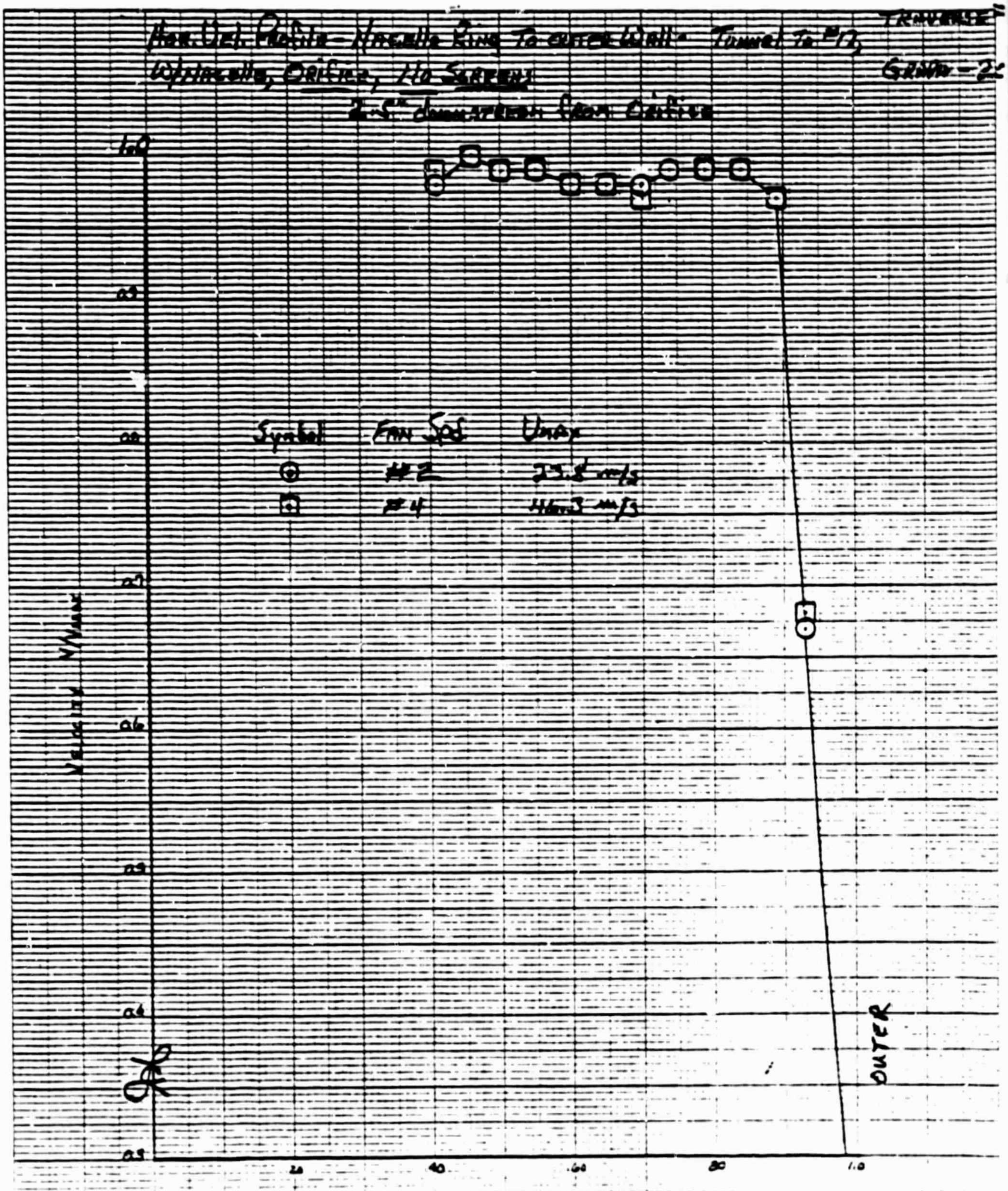
(b) Between outer wall and nacelle.

Figure 1. - (Concluded).



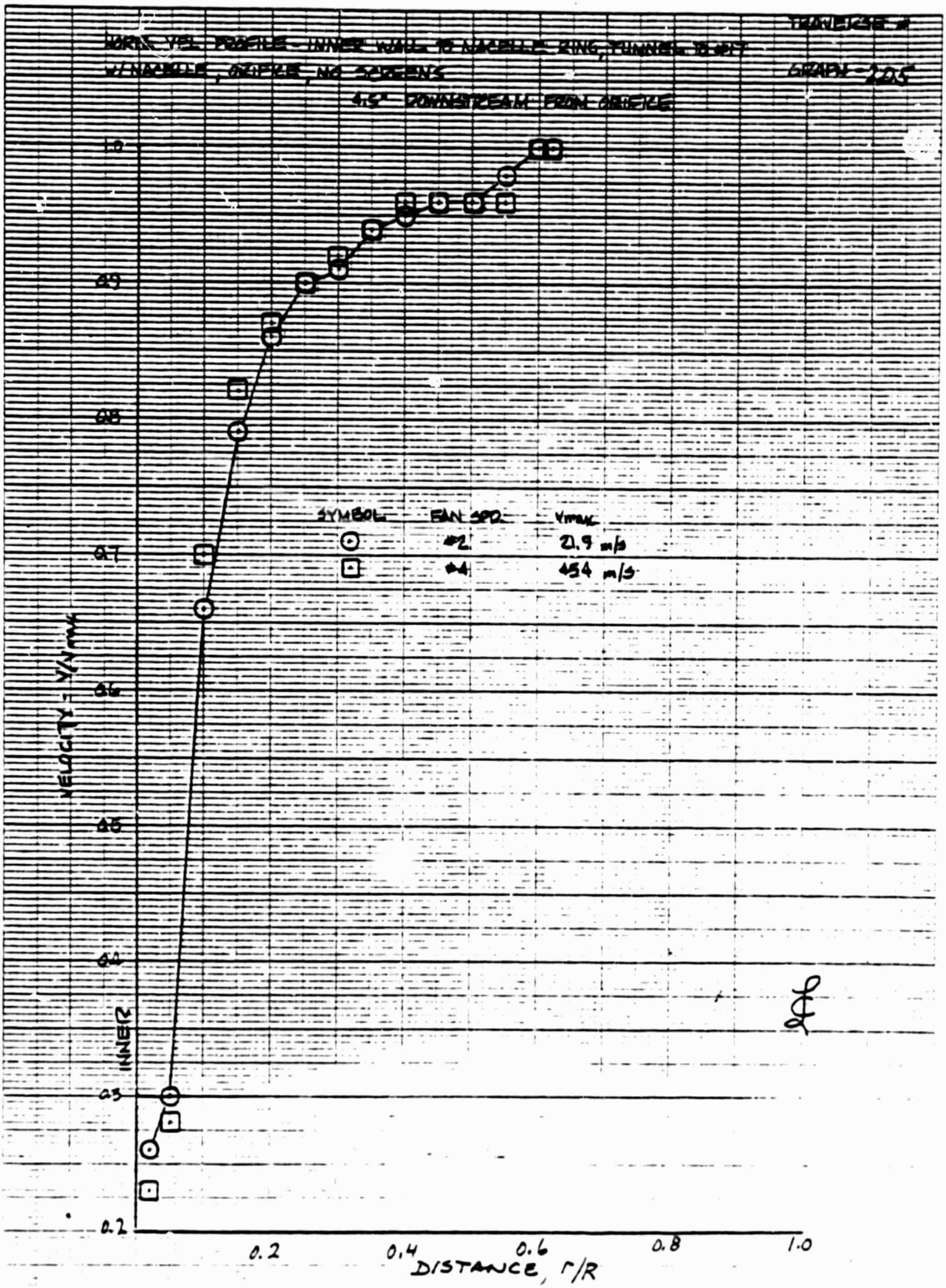
(a) Between inner wall and nacelle.

Figure 2. Flow distribution over nacelle at a location 6.35-cm (2.5-in.) downstream from T.S. 13 with an orifice of 48.3-cm (19-in.) diameter installed near T.S. 13.



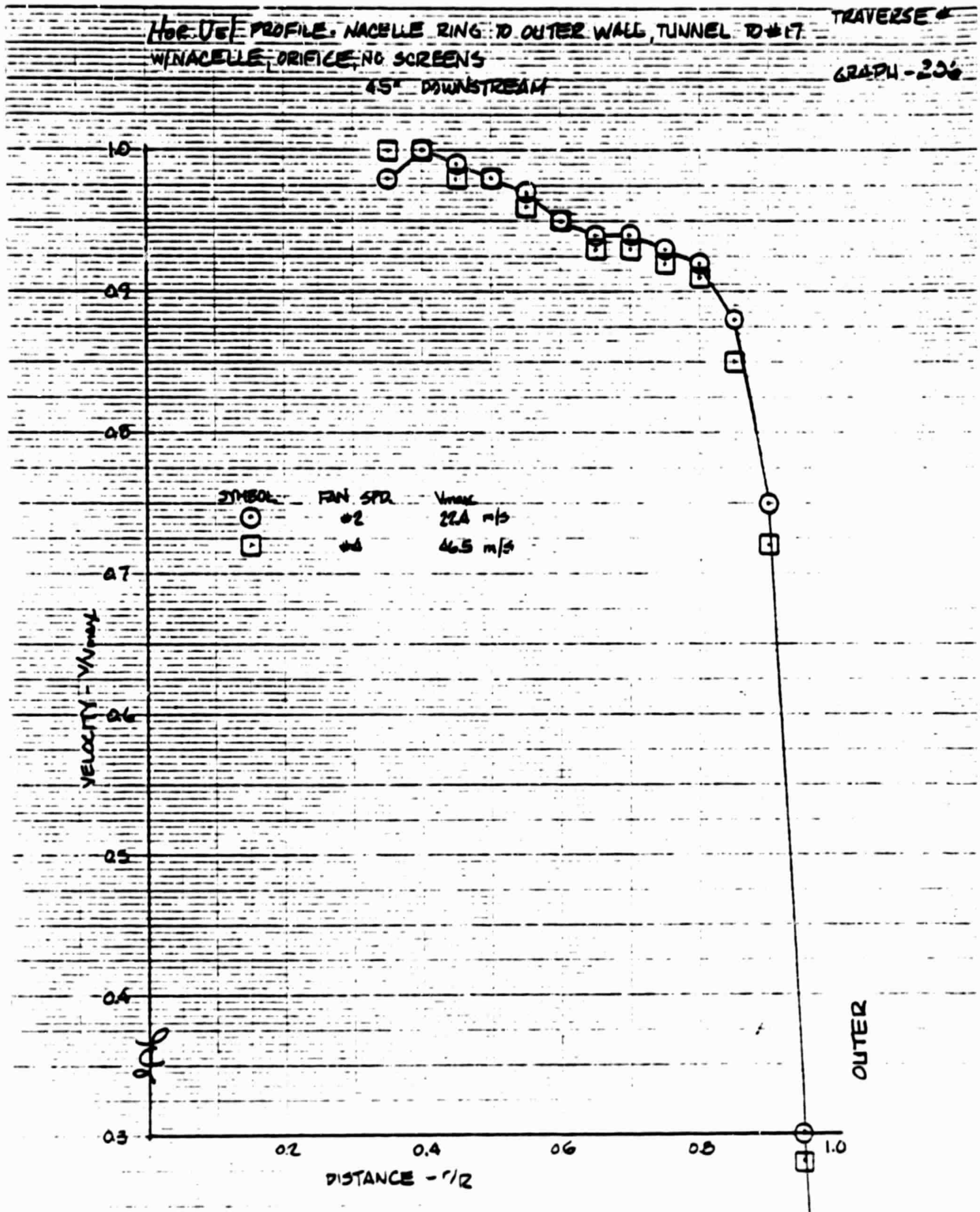
(b) Between outer wall and nacelle.

Figure 2. (Concluded).



(a) Between inner wall and nacelle.

Figure 3.- Flow distribution over nacelle at a location 11.43-cm (4.5-in.) downstream from T.S. 13.



(b) Between outer wall and nacelle.

Figure 3. (Concluded).

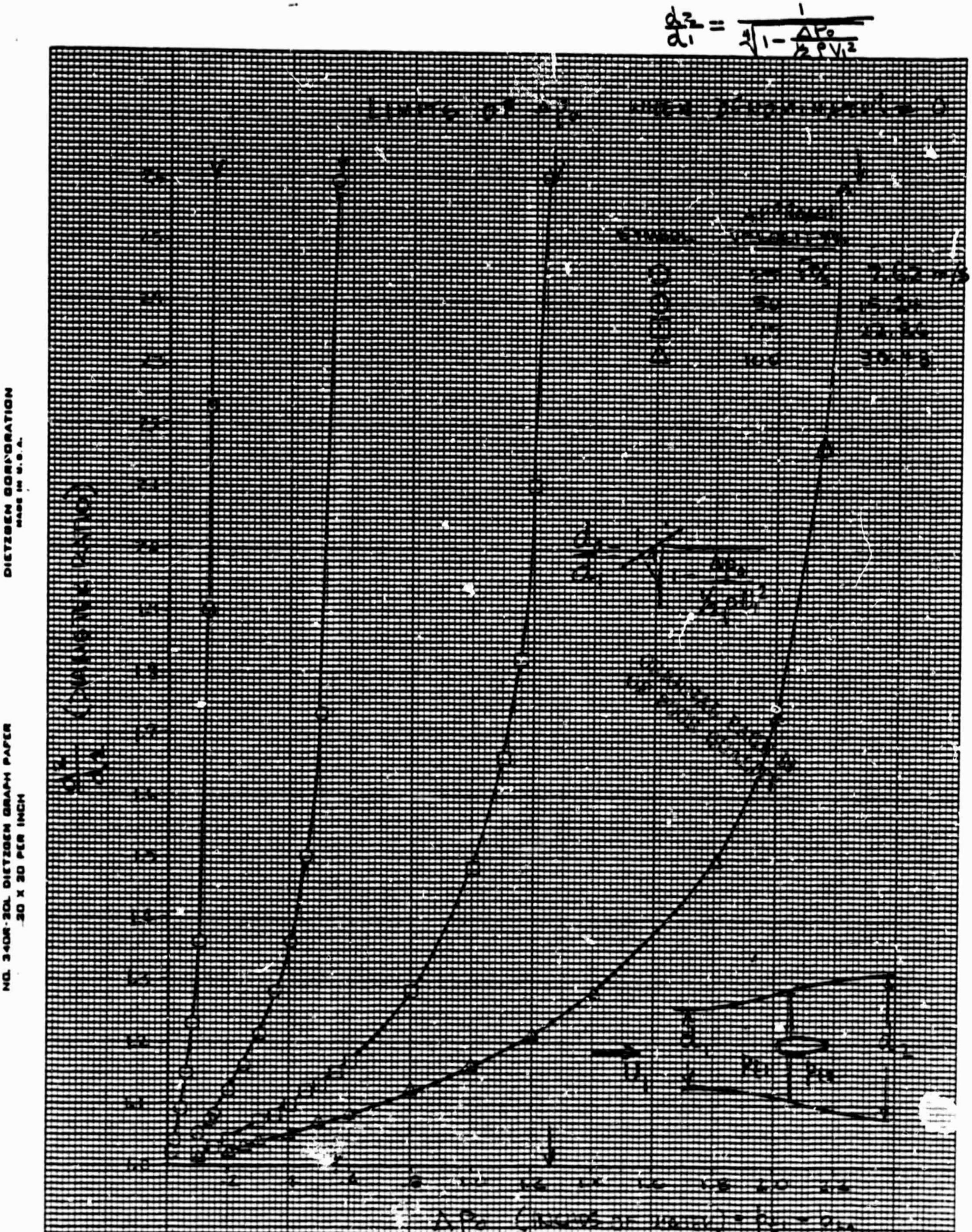


Figure 4. Theoretical prediction of the variation of spreading (d_2/d_1) of the stream flowing across a windmill with pressure drop for four different upstream velocities.

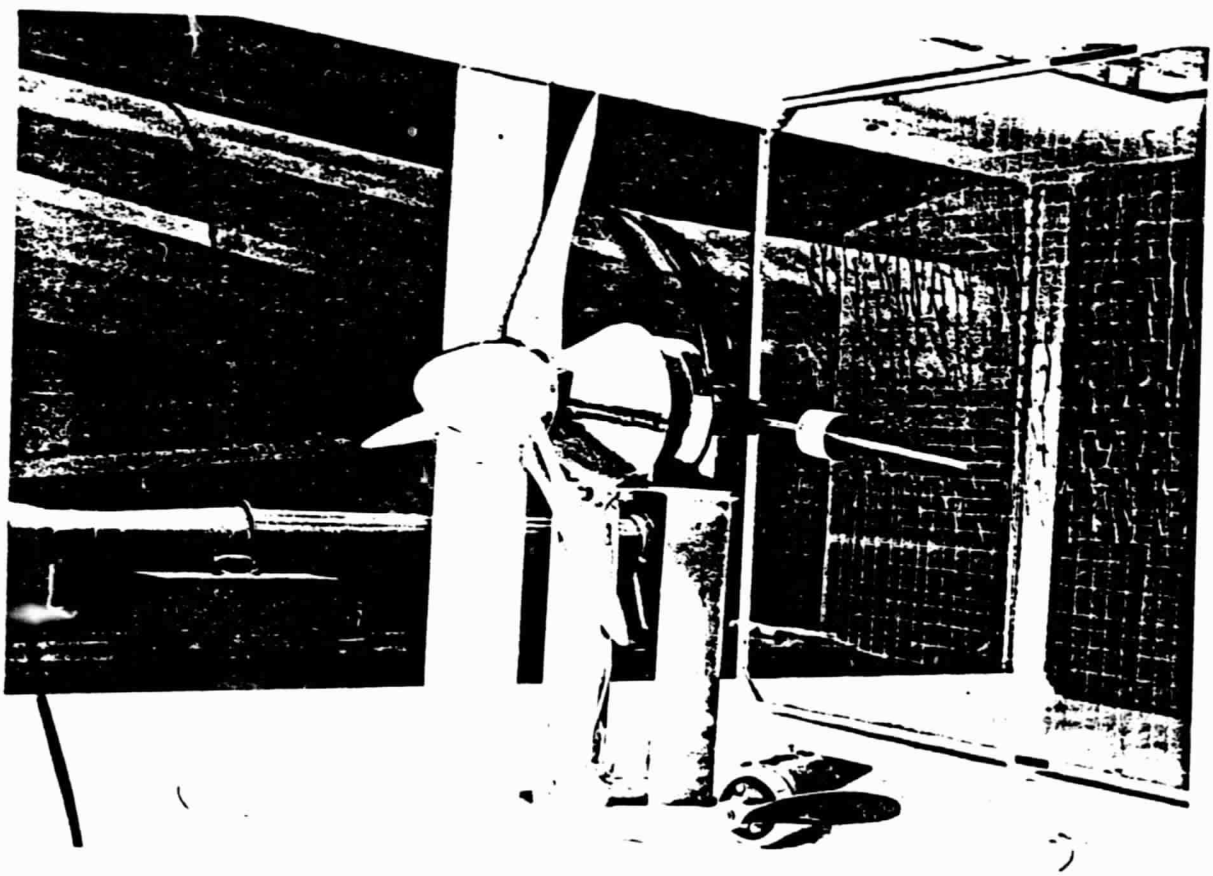
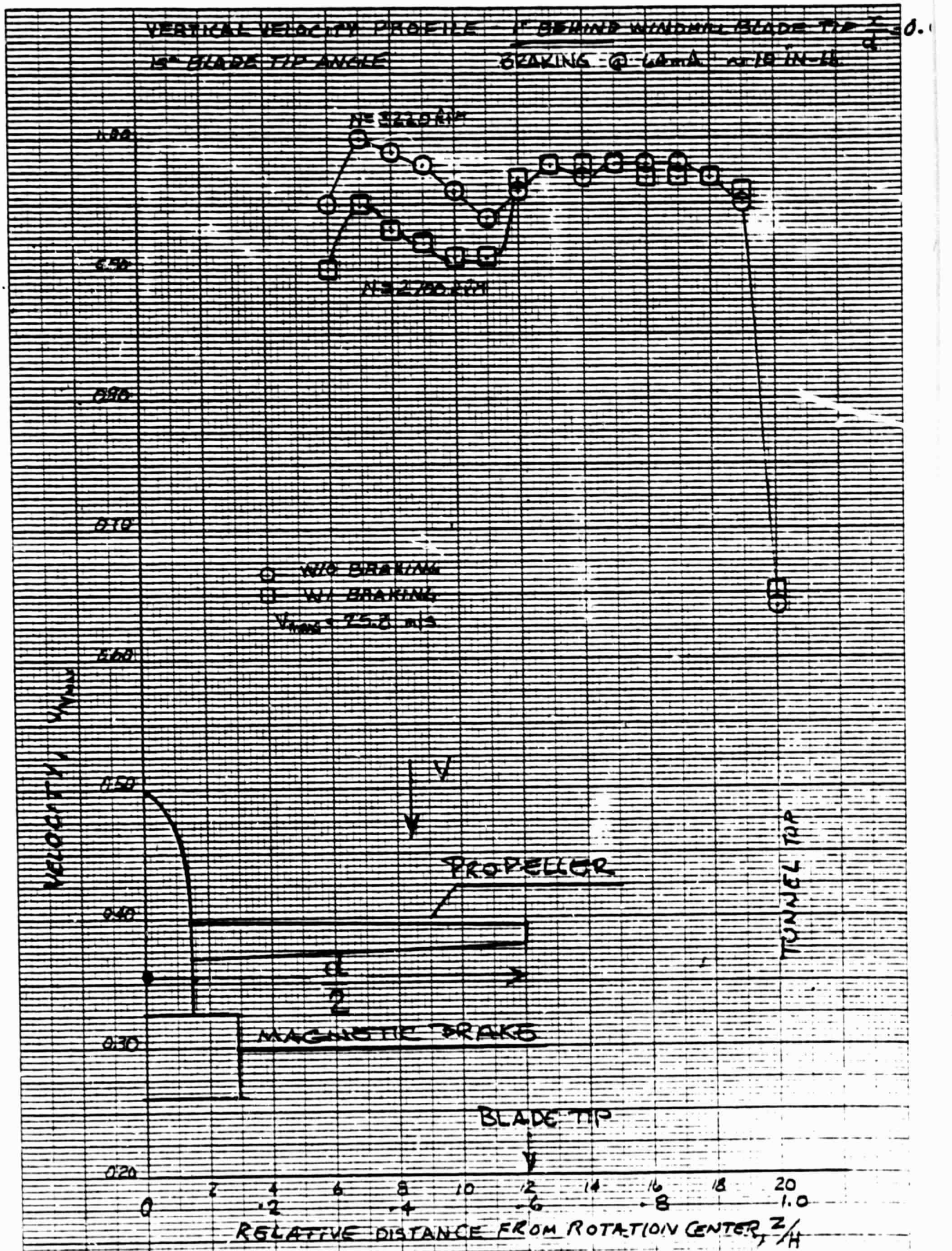


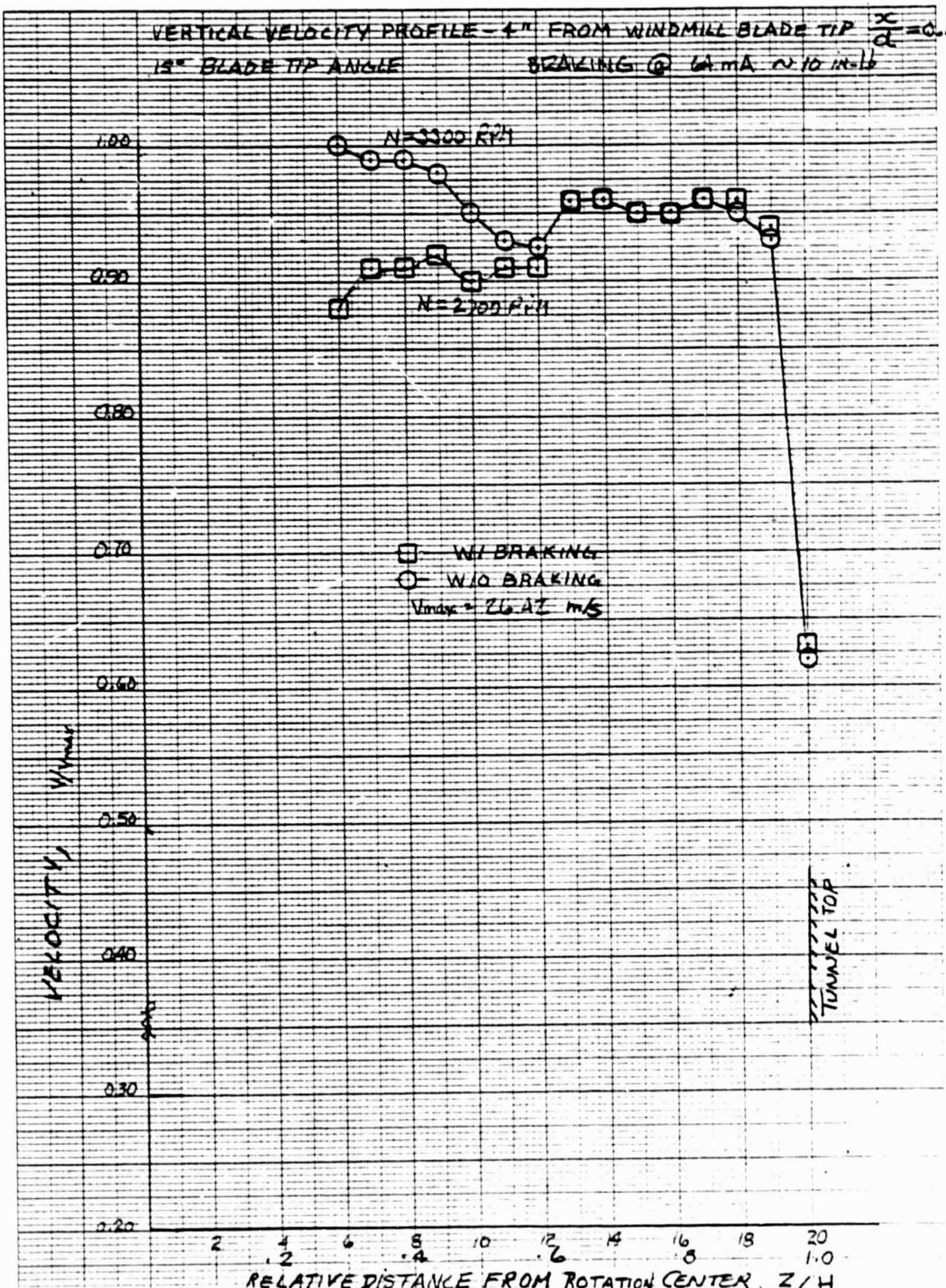
Figure 5. Photograph of a windmill attached to an electromagnetic brake (windmill diameter = 61 cm, brake diameter = 15.25 cm).



(a) Distance x/d = 0.04.

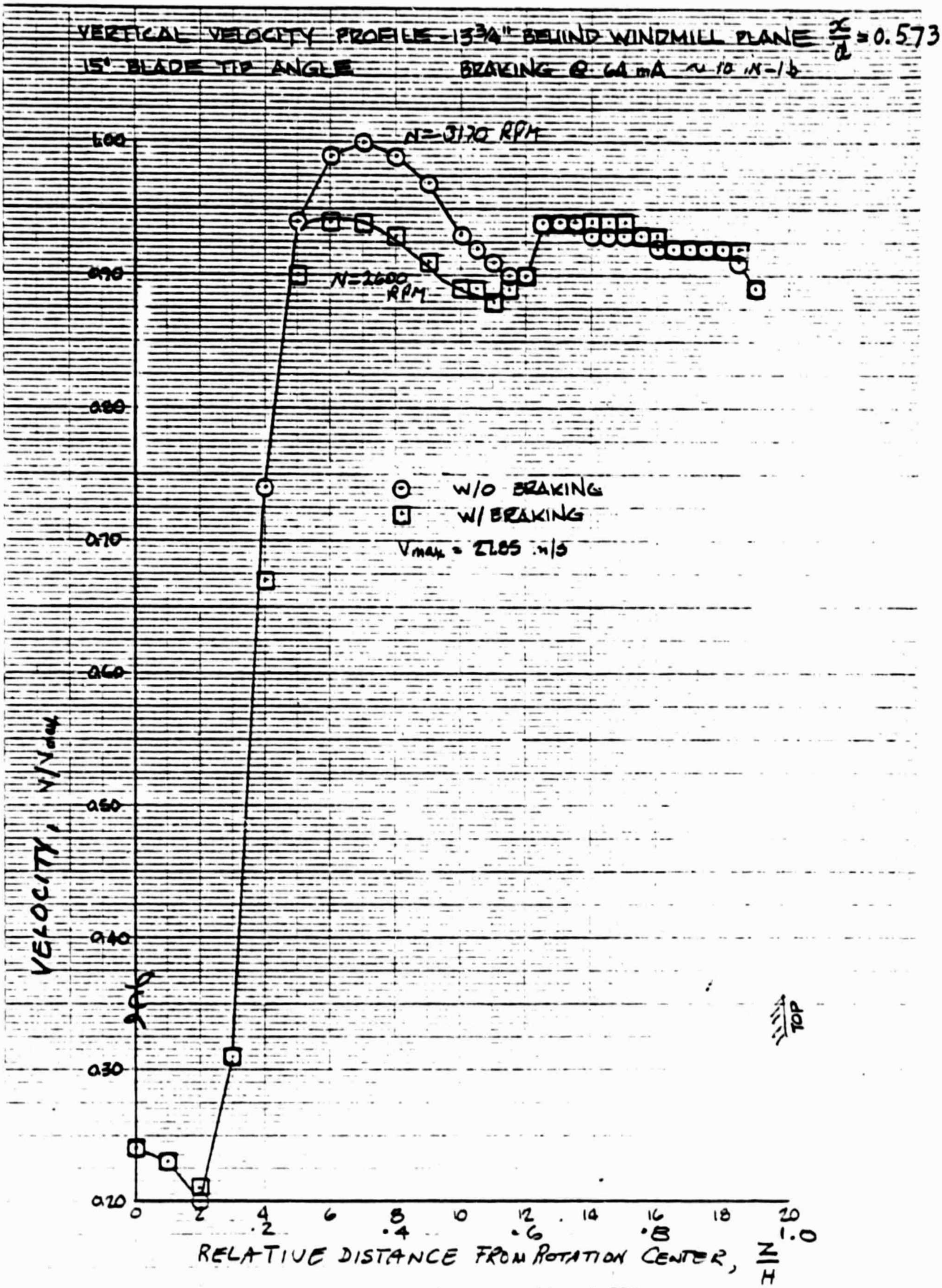
Figure 6. Variation of flow distribution with distance downstream from a three-bladed windmill/propeller) with and without a torque applied. (Torque applied was a constant 10 in. lb, blade tip angle = 15°).

V_{max} =



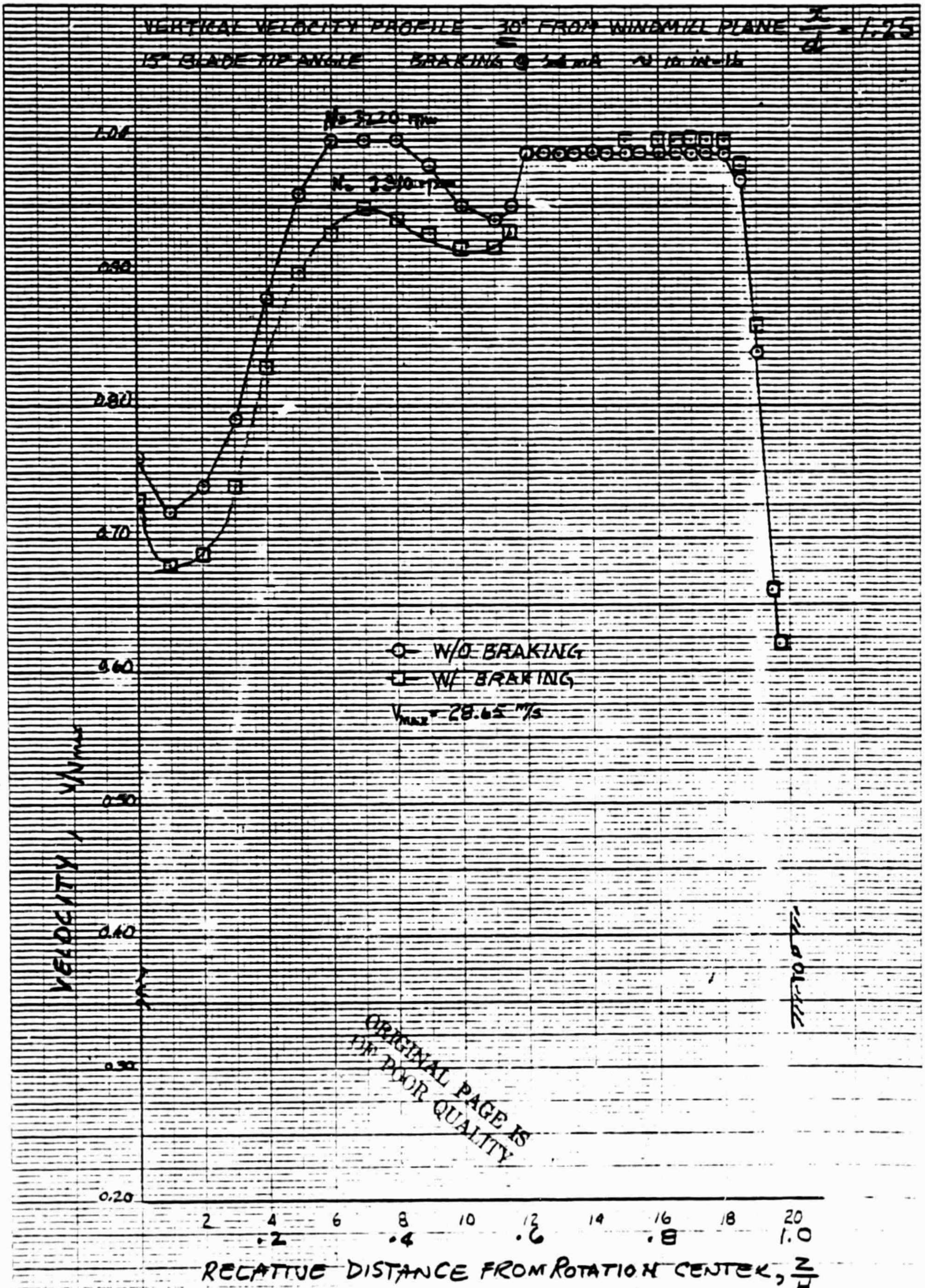
(b) Distance x/d = 0.167.

Figure 6. (Continued).



(c) Distance x/d = 0.573.

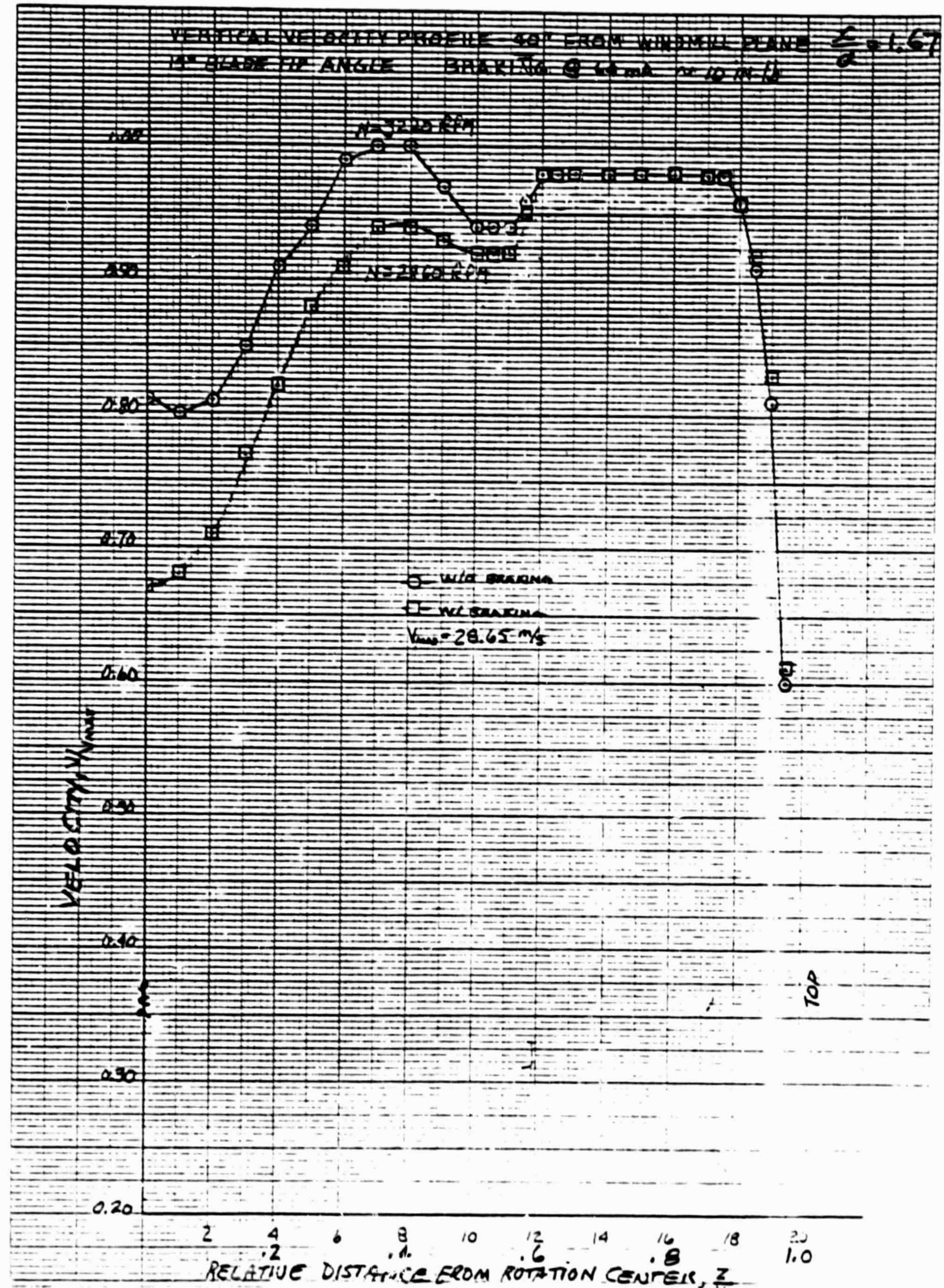
Figure 6. (Continued).



(d) Distance x/d = 1.25.

20 Squares to the Inch

Figure 6. (Continued).



(c) Distance x/d = 1.67.

20 Squares to the Inch

Figure 6. (Concluded).

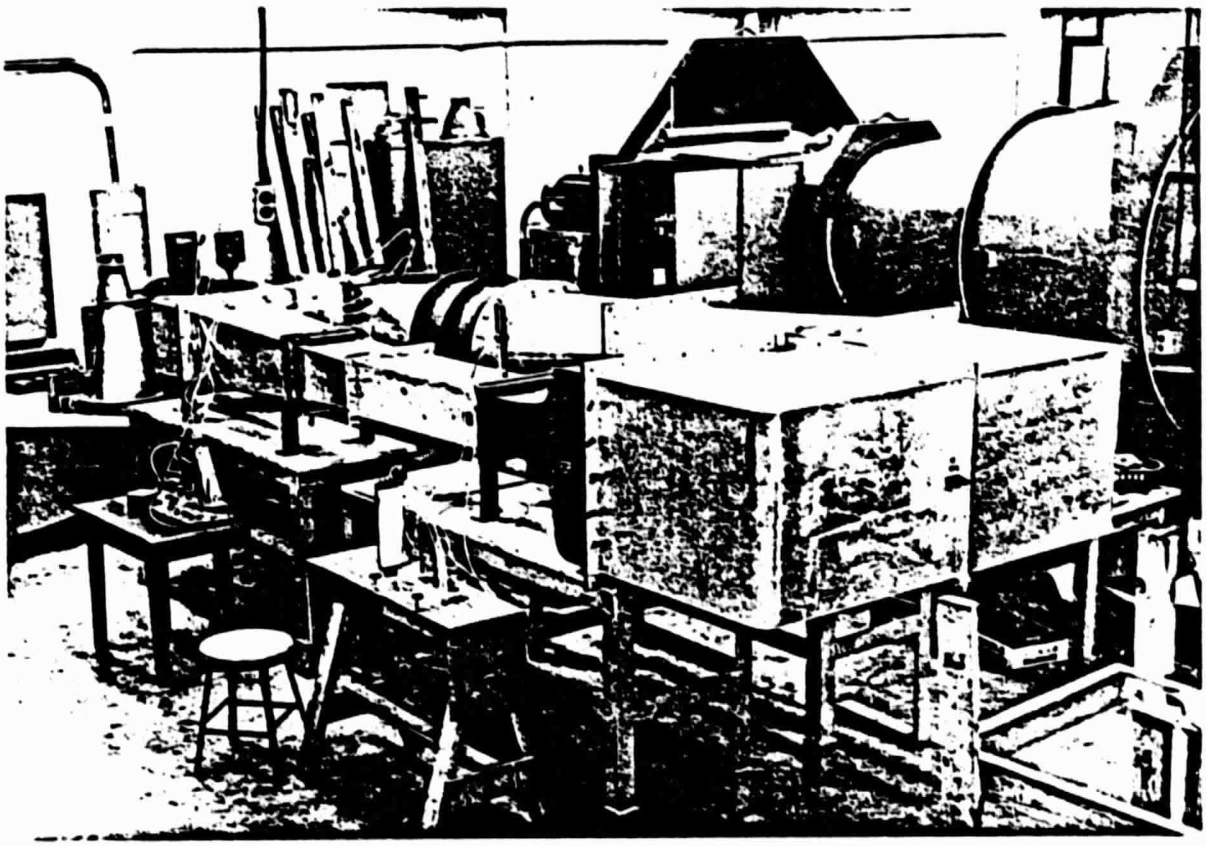
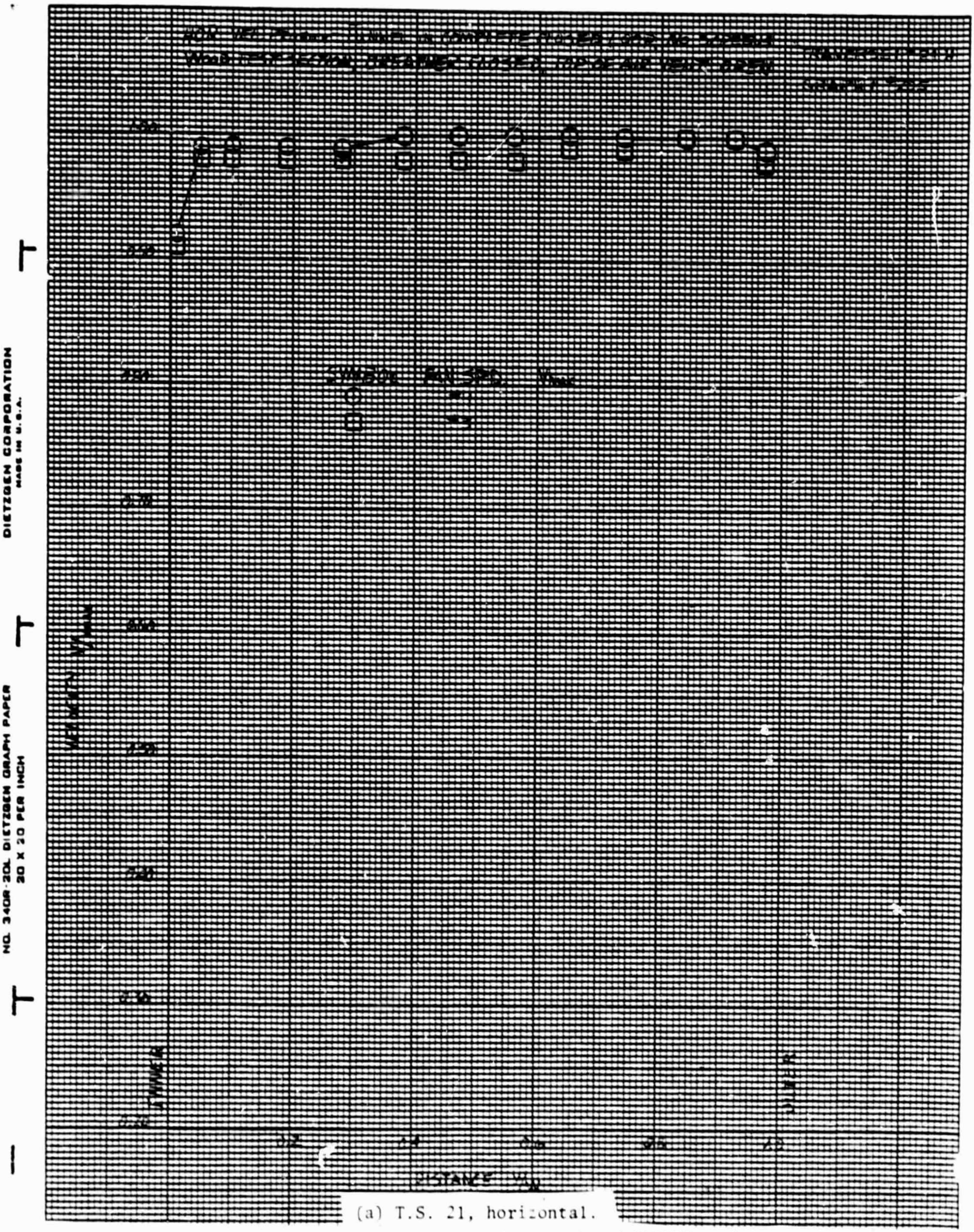
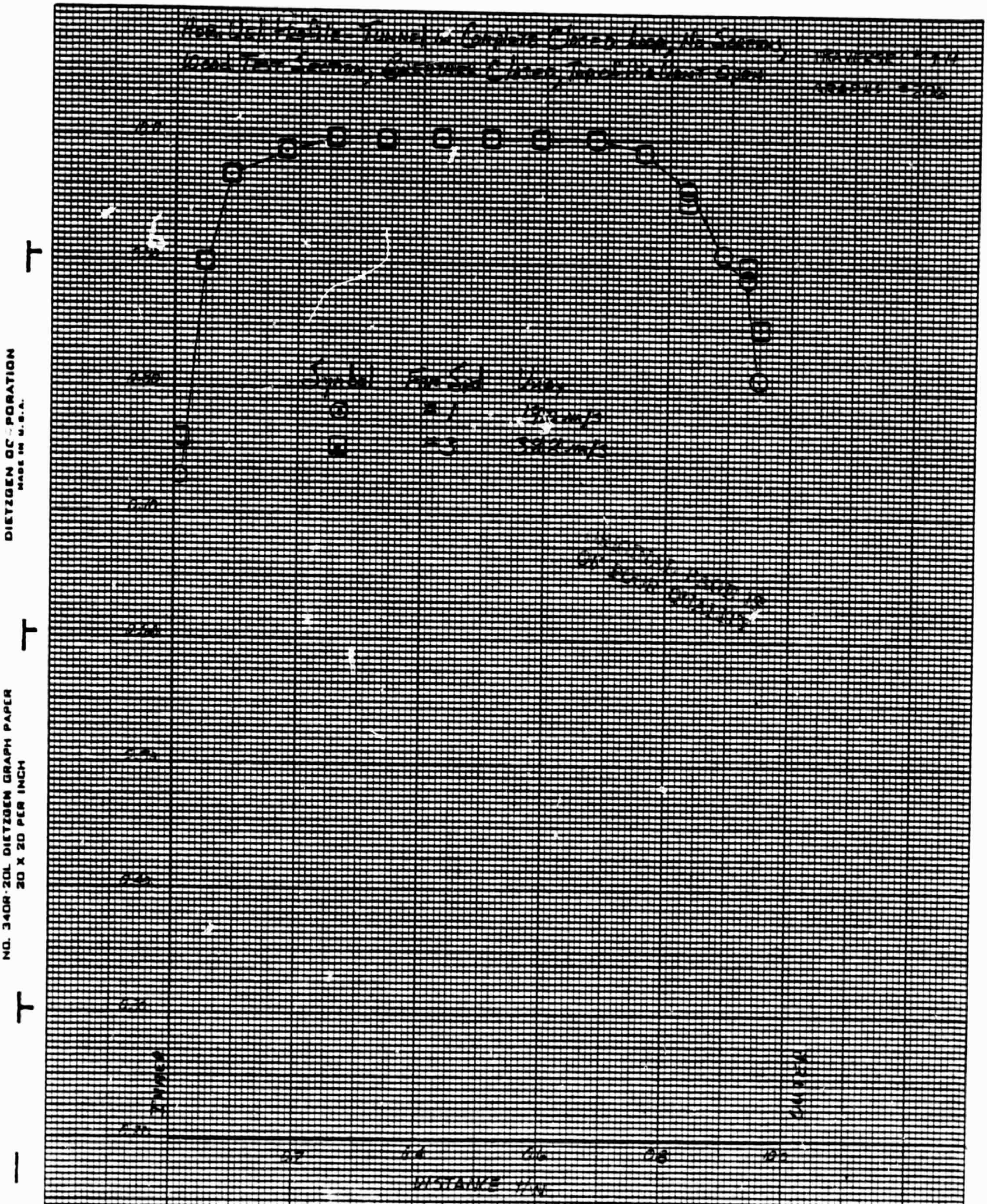


Figure 7. Photograph of the completed tunnel.



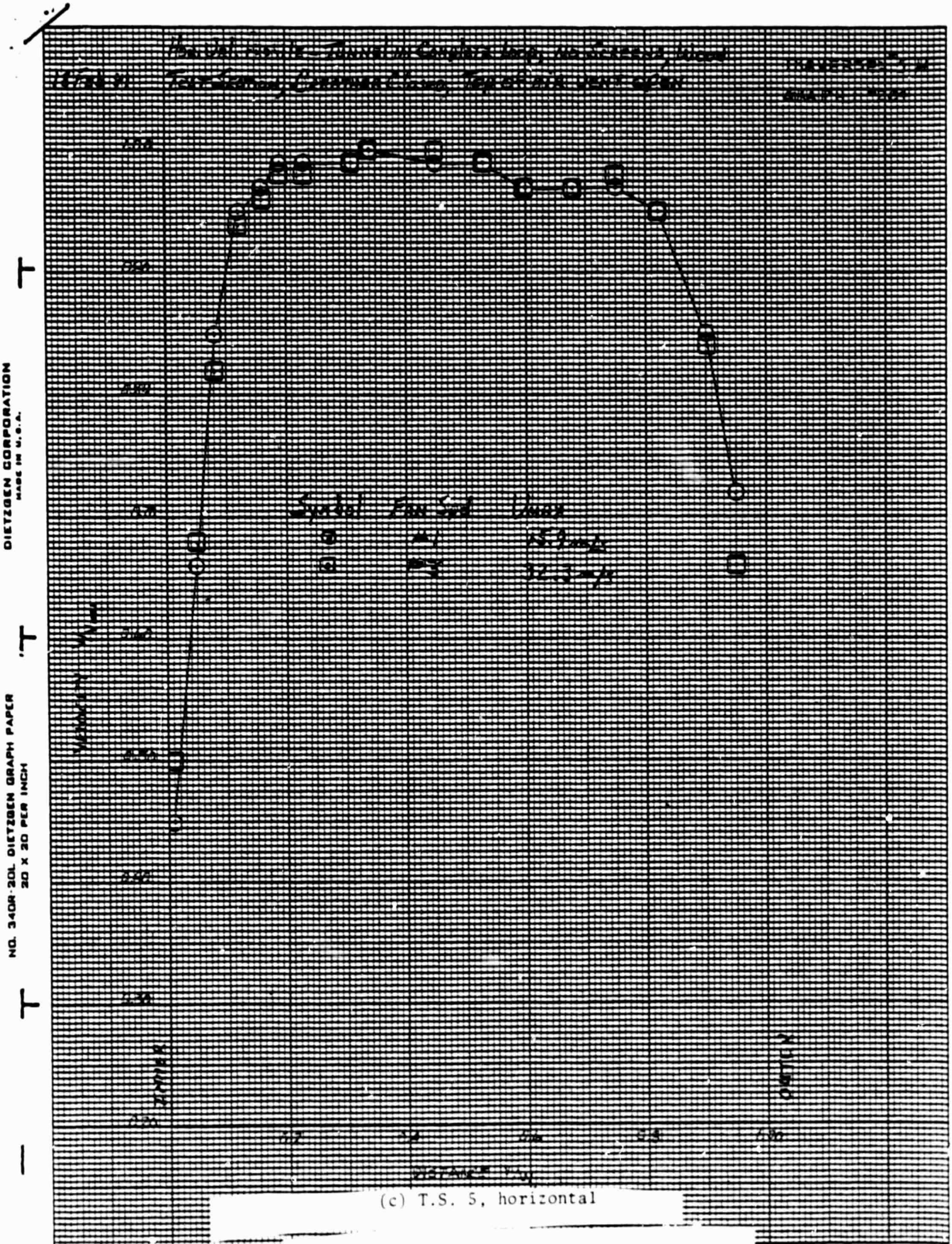
(a) T.S. 21, horizontal.

Figure 8. Velocity distribution samples on the completed V/STOL model tunnel at selected traverse stations with test section and air breather both closed. (See Figure 9 for location of traverse stations).



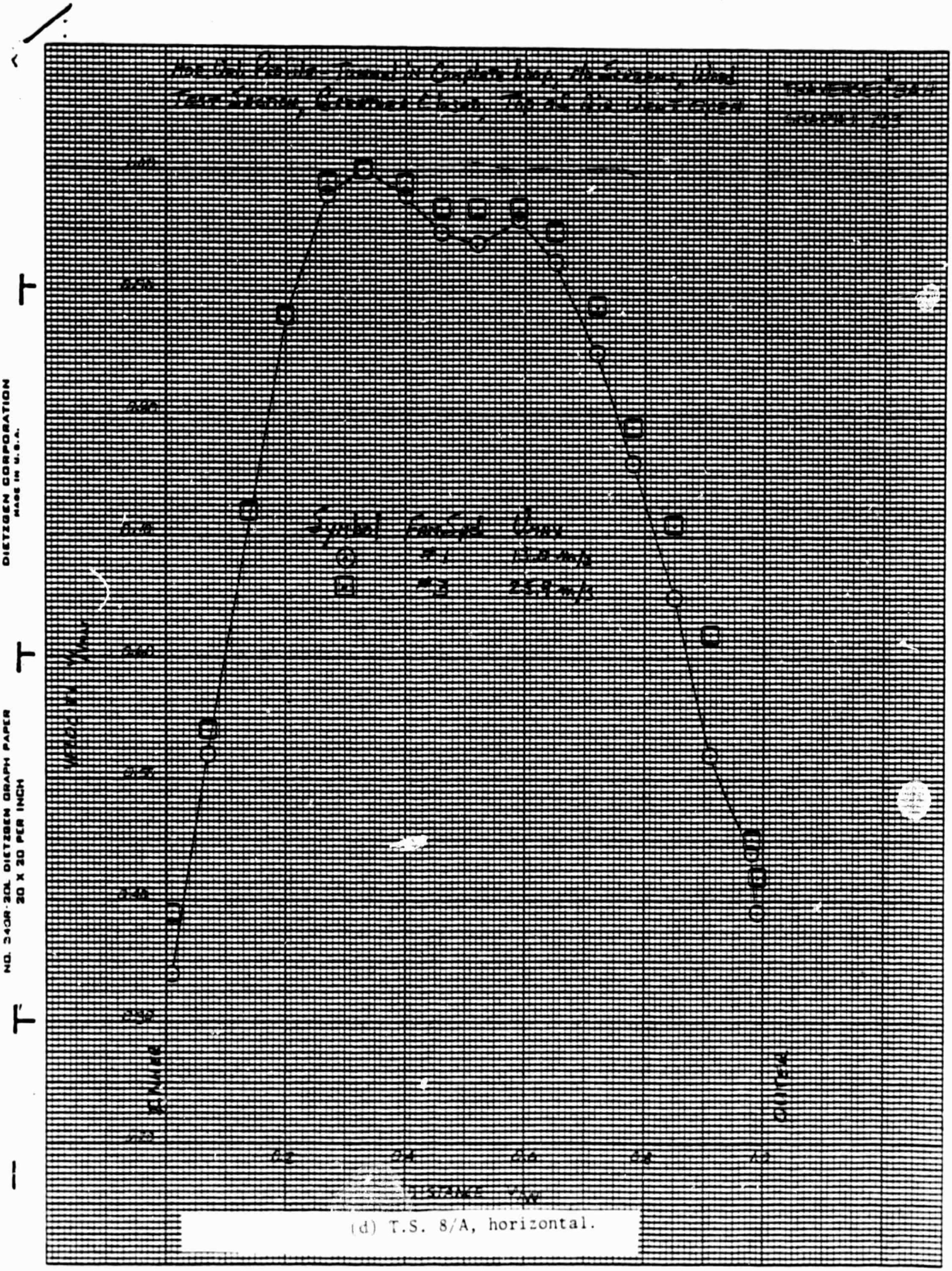
(b) T.S. 1, horizontal.

Figure 8. (Continued).



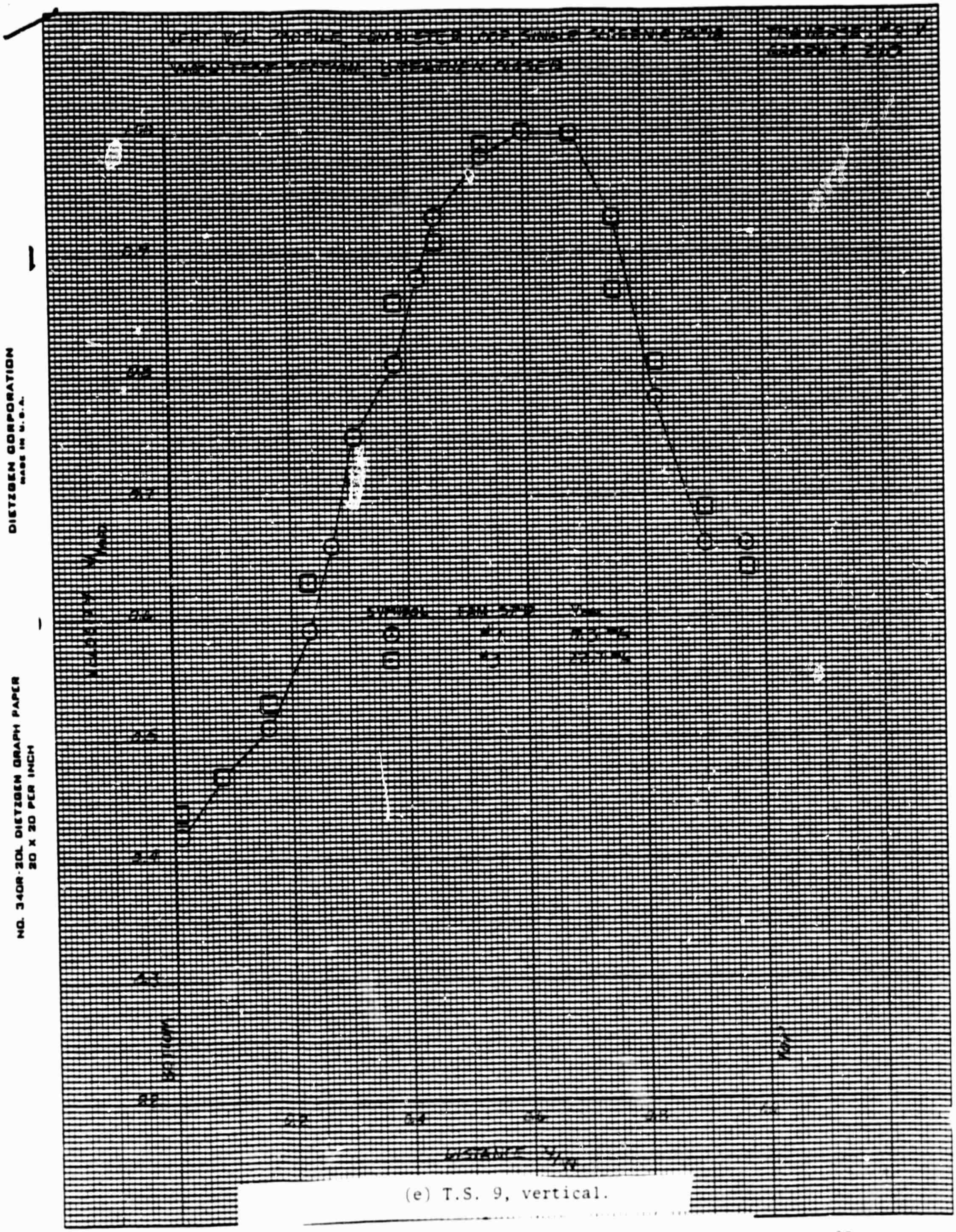
(c) T.S. 5, horizontal

Figure 8. (Continued).



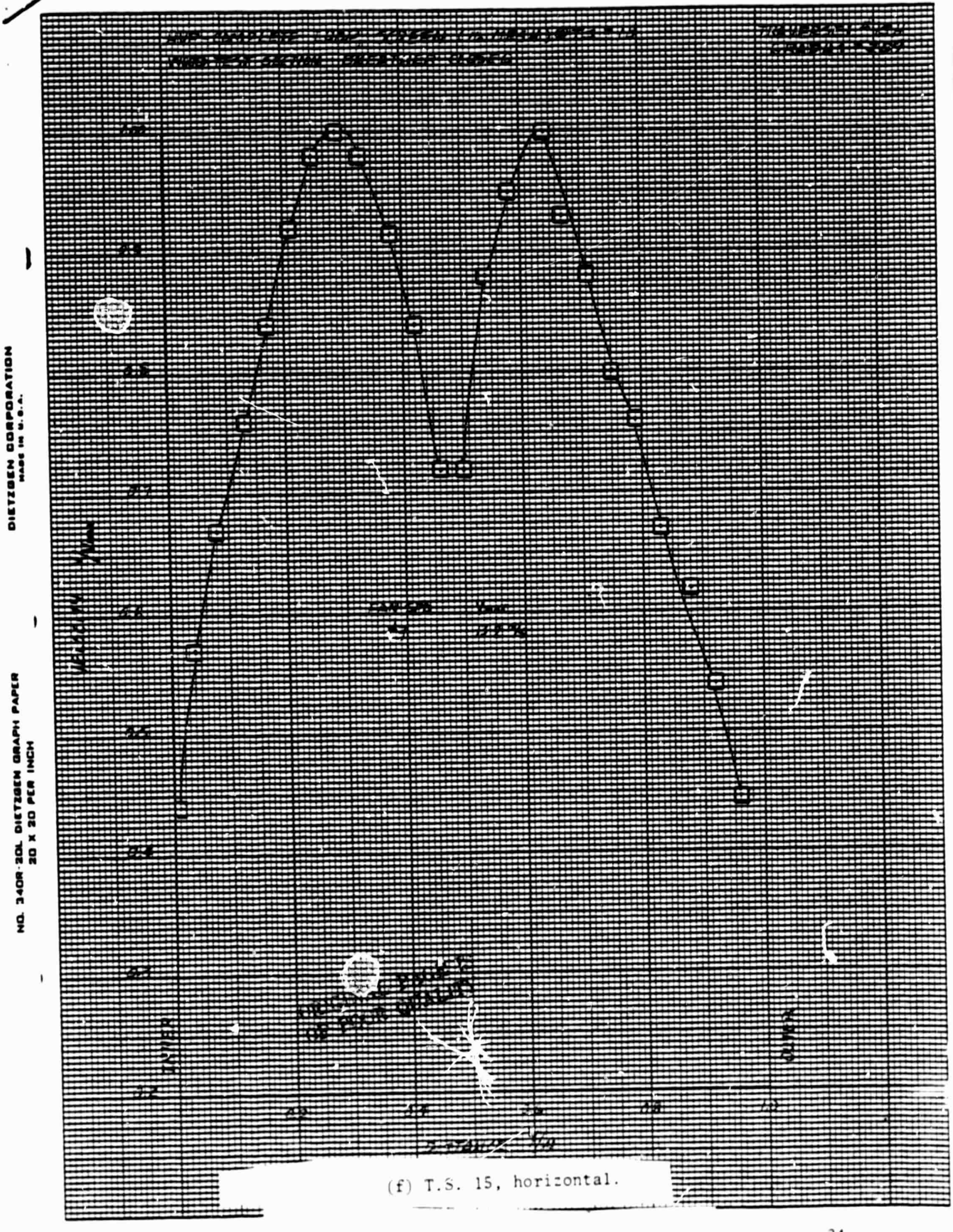
(d) T.S. 8/A, horizontal.

Figure 8. (Continued).



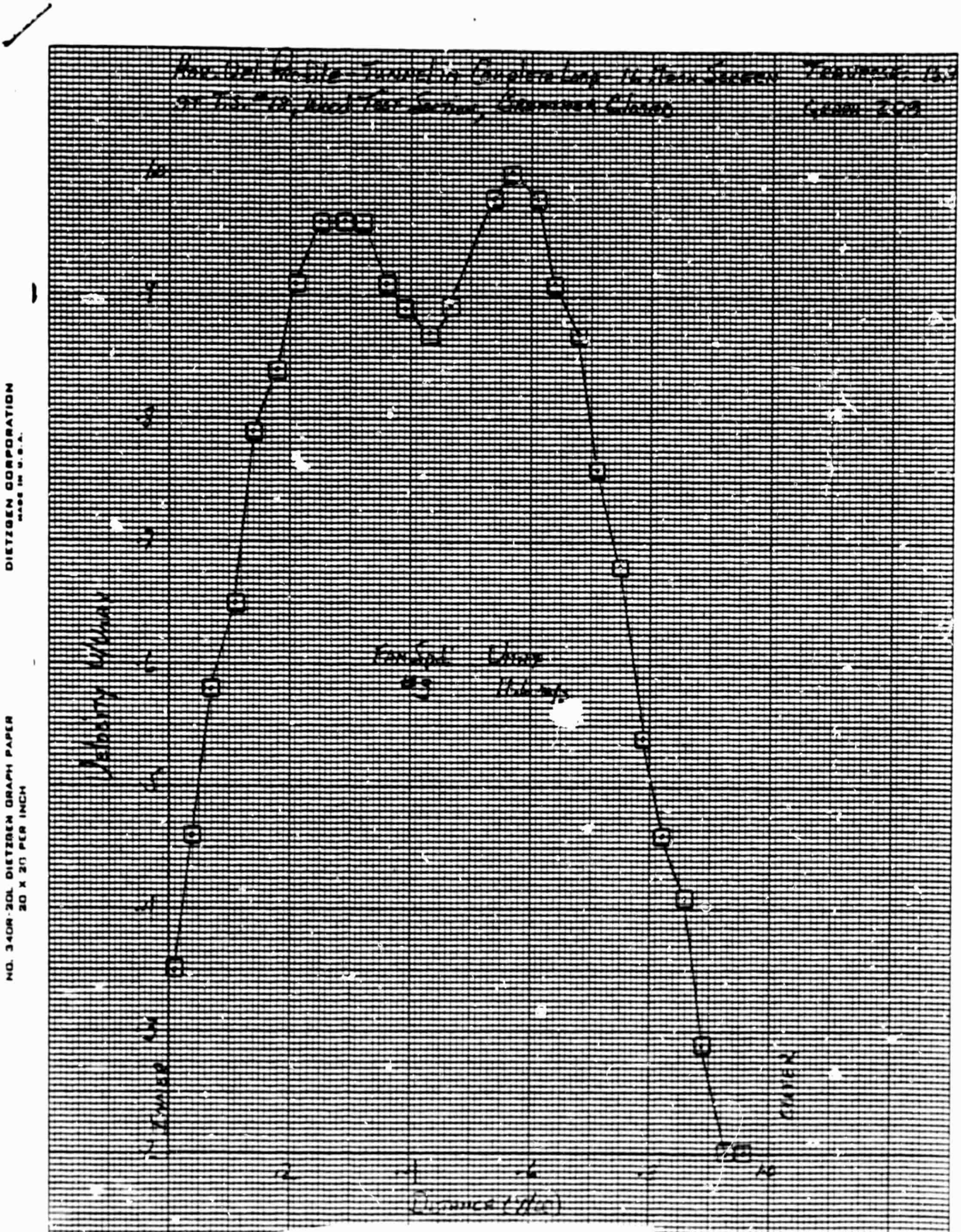
(e) T.S. 9, vertical.

Figure 8. (Continued).



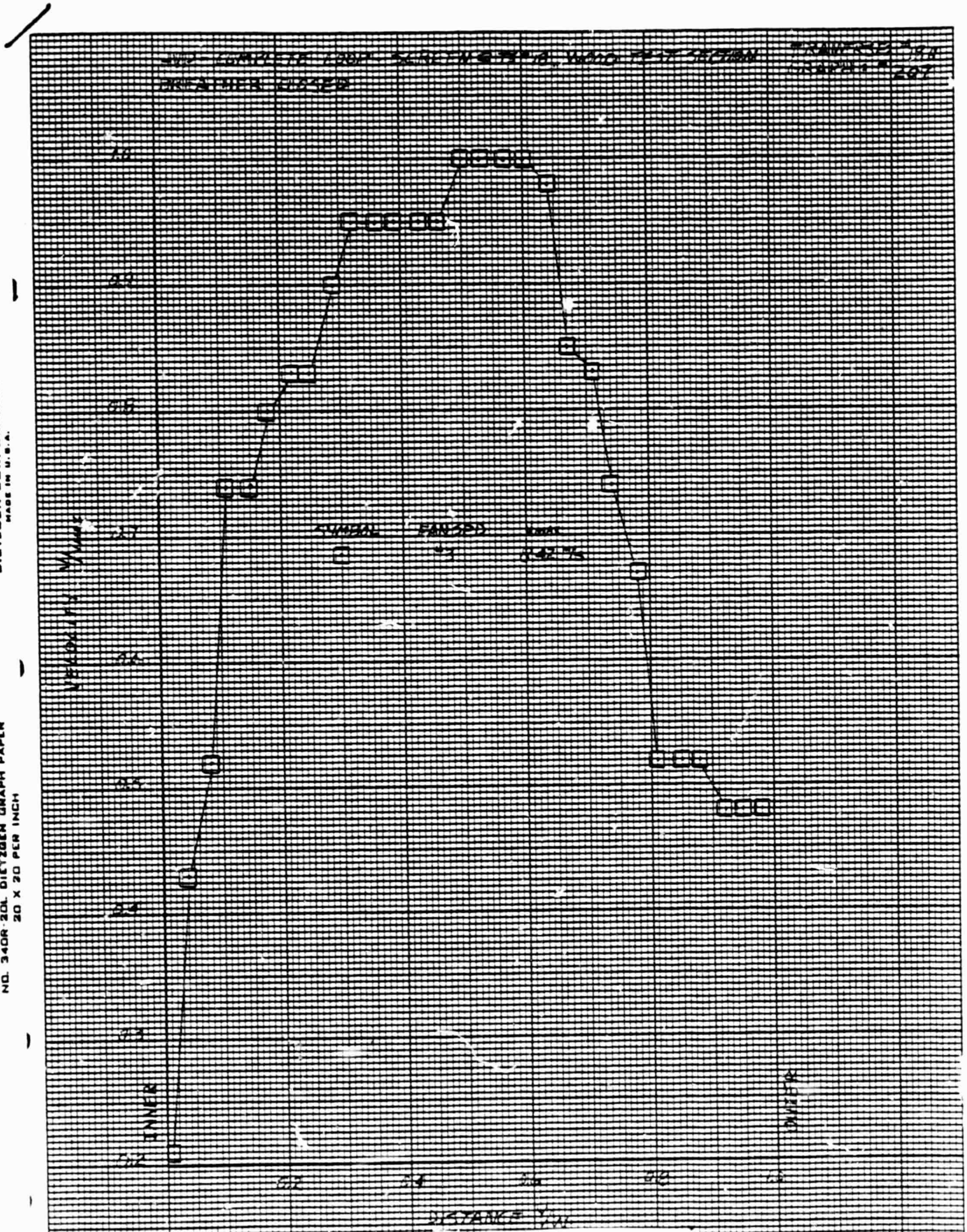
(f) T.S. 15, horizontal.

Figure 8. (Continued).



(g) T.S. 16, horizontal.

Figure 8. (Continued).



(h) T.S. 18, horizontal.

Figure 8. (Concluded).

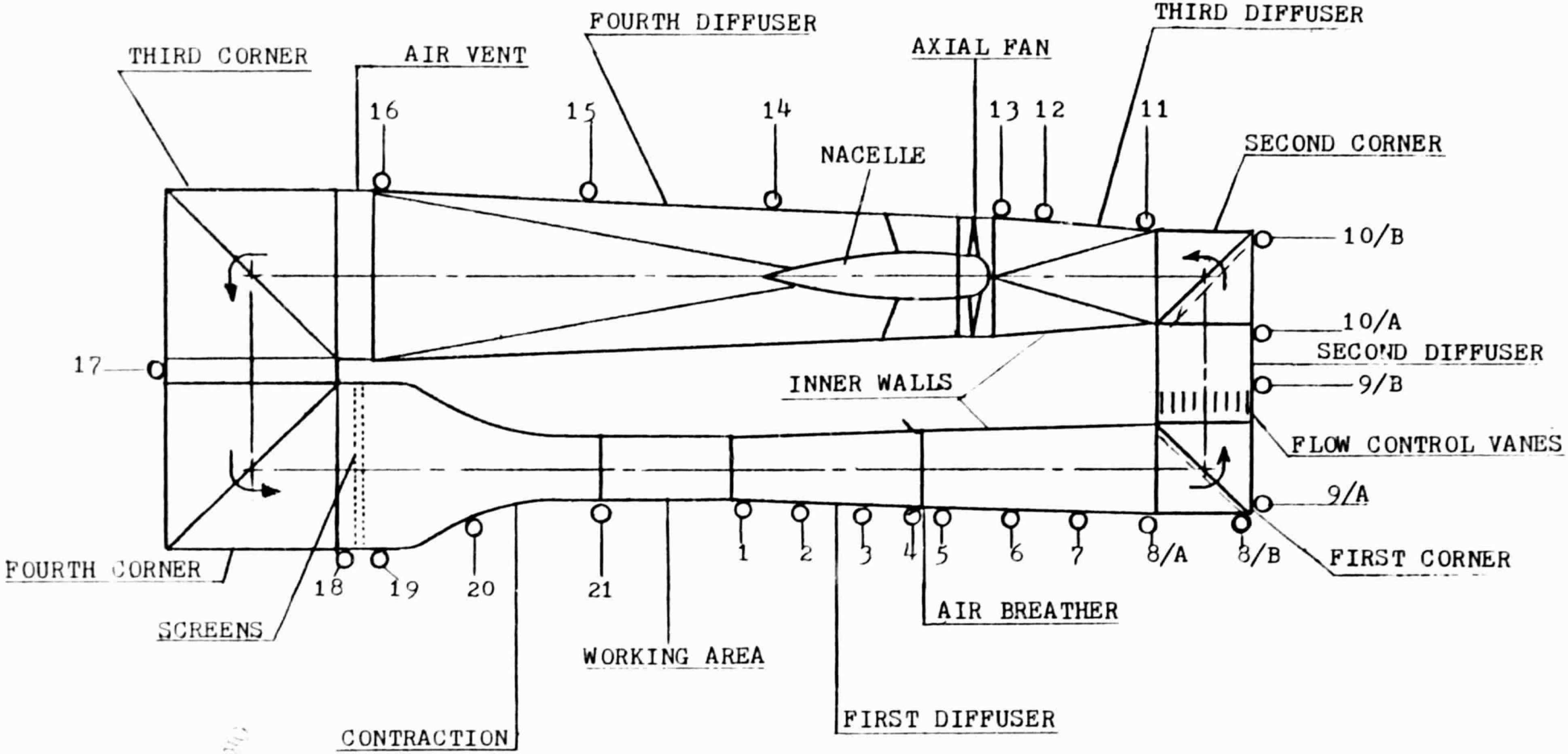


Figure 9. Plan view of the V/STOL tunnel.

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