CONF-770921/2
UC-60

Third WIND ENERGY WORKSHOP *Volume 2*

Proceedings of the Third Biennial Conference and Workshop on Wind Energy Conversion Systems

September 19-21, 1977
Washington, DC

Coordinated by
JBF Scientific Corporation

for
U.S. Department of Energy
Assistant Secretary for
Energy Technology
Division of Solar Technology
Washington, DC 20545

Under Contract No. E(49-18)-2521

May 1978

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 (2-part set; sold in sets only)

Stock No. 061-000-00089-5

SUMMARY OF RECENT PROGRESS ON TORNADO-TYPE WIND ENERGY SYSTEM

James T. Yen

Research Department
Grumman Aerospace Corporation
Bethpage, New York 11714

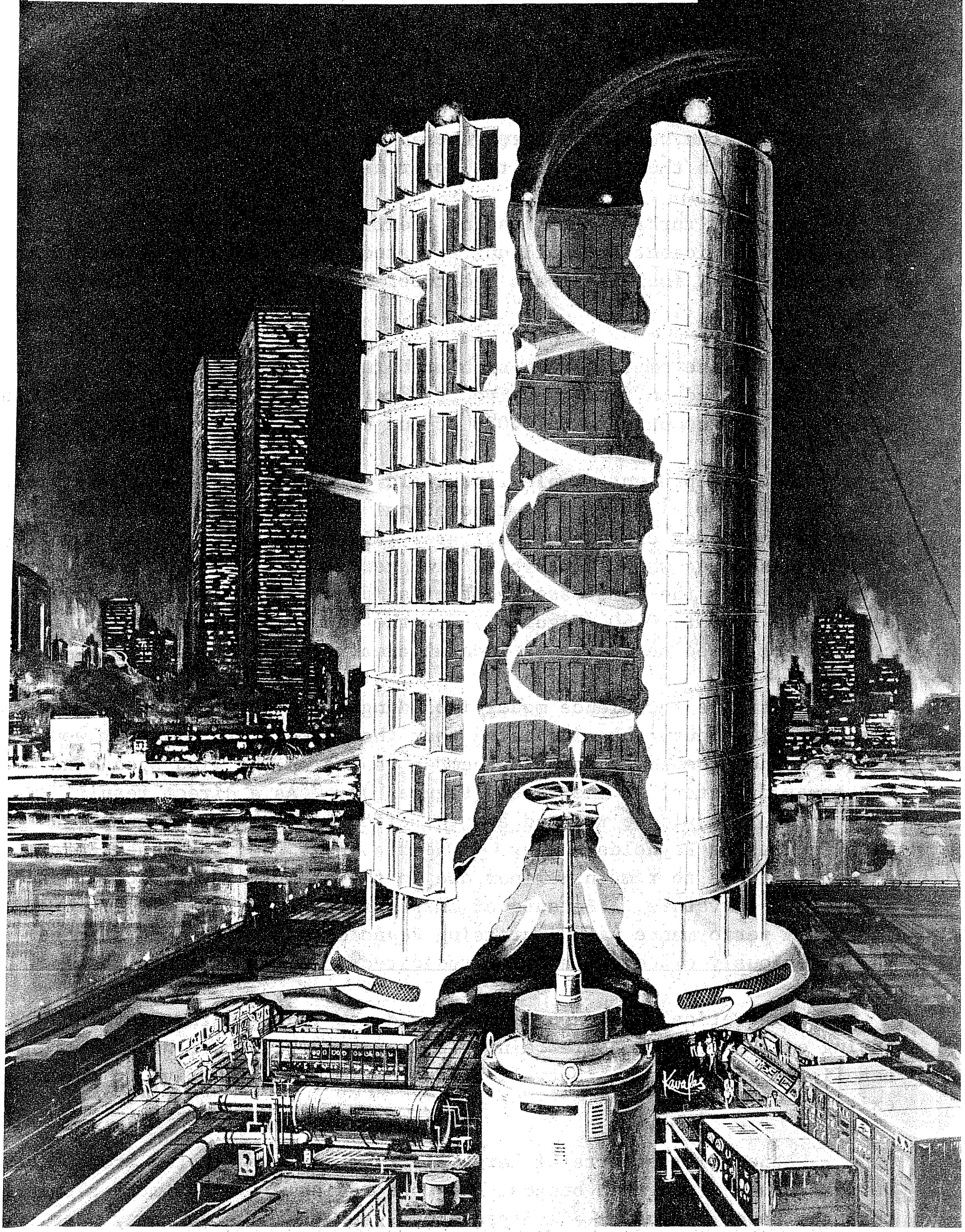
July, 1977

The Tornado-Type Wind Energy System is one of several Advanced and Innvative Concepts being investigated under ERDA's Wind Energy Program as potential ways to reduce the cost and broaden the usability of wind energy. This system (see Fig. 1) uses a large hollow tower to form an internal vortex, and the low pressure at the core of the tower provides an effective and low-pressure exhaust reservoir for the turbine, which accepts a separate ram air inlet supply. The tower serves as a stationary and omni-directional collector and concentrator capable of collecting immense amounts of wind energy and concentrating the collected energy into a high-power-density turbine. This system provides unique advantages of a small, compact, vertical-axis, enclosed and high-efficiency turbine as well as a stationary, omni-directional and modularized tower. The components of the modularized tower can be mass produced on assembly lines, subassembled in the factory and stacked up in the field for low-cost manufacturing, construction and maintenance, and for fast delivery and early return on investment. This system promises a structurally rugged and stable design for both on-land and off-shore installations. Based on this design, large and low-cost multi-megawatt wind energy systems may be developed and constructed for the utilities, and small and economically competitive systems may be provided for individual farms and homes. We hope that this system will enable us to bring out fully the immense potential of wind energy.

This presentation summarizes our recent progress. Analytical investigations of several very challenging fluid mechanical problems are being carried out, but it will be some time before all of the flow processes involved will be well known enough to yield a highly accurate analytical prediction of performance and to greatly improve our existing scaling laws. A variety of wind tunnel models have been designed and built and some testing at small scale has been conducted using screens to simulate the turbines.

Although this investigation is still in its early stages, the prospect for the Tornado-Type Wind Energy System looks encouraging. Highlights and key issues are listed below:

Fig. 1 Artist's Conception of a Tornado-Type Wind Energy System



o Detailed pressure surveys (Figures 2 to 4) on the tower bottom wall with various screen-simulated turbines and small towers indicate that overall, the vortex is strengthened by the presence of the turbine as compared with the case when the tower has a solid bottom.

o Optimal turbine disk loading coefficient for maximum values of the power coefficient in small units tested is found to be between 2 and 5 (Figure 5); it increases when the turbine size is reduced relative to the tower size.

o For these small screen-simulated turbines, the measured power coefficient based on the tower frontal area has reached a value of 0.066 (Figure 5), as compared with 0.020 of our earlier results (Ref. 1).

o Two independent simple flow field analyses (Refs. 2 and 3) yield the same value of 1.54 for the theoretical maximum power coefficient based on the tower cross sectional area (Figure 6) and 24.1 based on the turbine disk area when the turbine diameter is one-fourth of the tower diameter. For the same case, another simple analysis (Ref. 4) gives a range of 0.30 to 0.60 (Figure 7) for the theoretical maximum power coefficient based on the tower frontal area.

o A simple turbulence model including the stabilizing effects of the streamline curvature indicated that the vortex core diameter would decrease when the tower Reynolds number (based on the wind speed and the tower diameter) is increased (Figure 8). As a direct result, the core pressure would be reduced and the effect of the vortex enhanced with increasing Reynolds number. One reason is that the inner core structure tends to remain laminar due to the stabilizing effects of the streamline curvature. Because of this effect, the predicted improvement in system performance with increasing Reynolds number is much stronger than previously expected, and is predicated on a more rational basis.

o Theoretical and experimental evidence indicate that turbines having exit swirls that are reinforing to the vortex core have a strongly beneficial effect on the overall system performance relative to screen exits.

o Beneficial effects of large size are expected in two areas; the vortex should strengthen because the core radius will grow more slowly than the tower radius as discussed above, and the high velocity near the core causes a reduction in centerline density which in turn adds a bouyancy effect to the vortex pumping action. As in a chimney, this latter effect increases with tower height.

References

1. Yen, J.T., "Tornado-Type Wind Energy System: Basic Consideration," ASME Paper 76-WA/Ener-2 (1976).

2. Mellor, G., unpublished paper.

3. Hsu, C.T., "Power Efficiency of a Wind Vortex Turbine," unpublished paper.

4. Loth, J.L., "Betz-Type Limitation of Vortex Wind Turbines," paper submitted for publication in Wind Engineering.

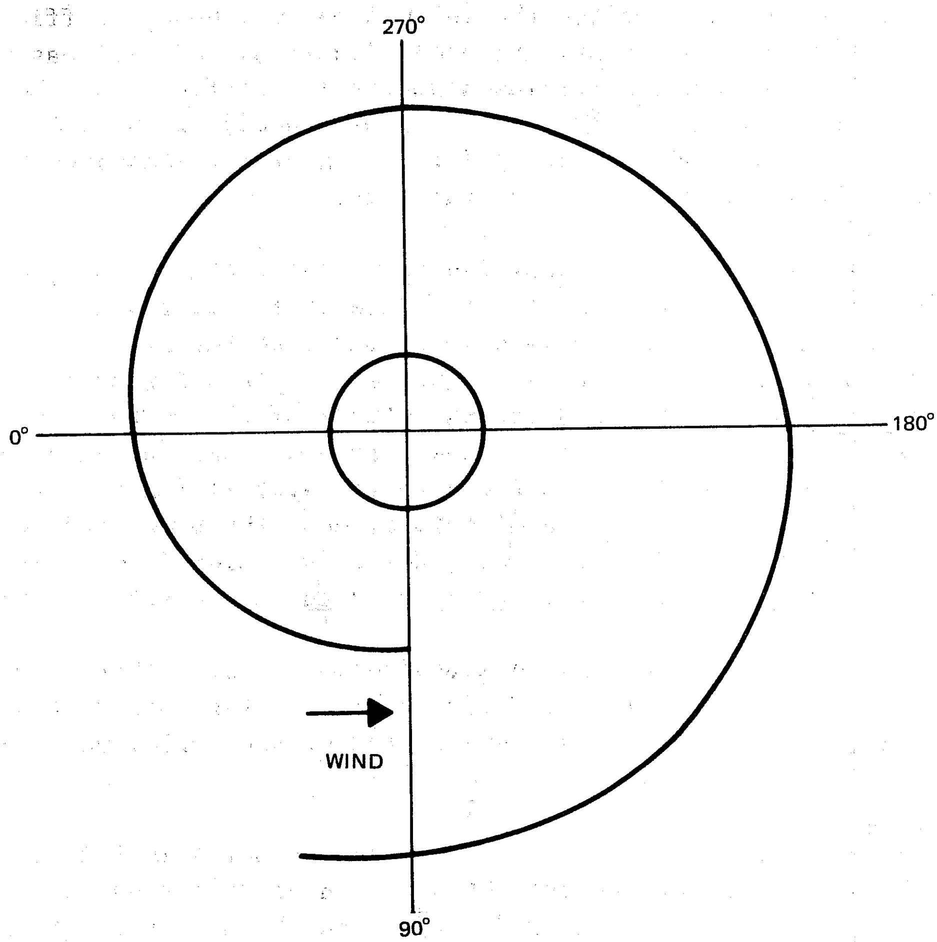


Fig. 2 Defining the Coordinate System for the Tower Bottom Wall

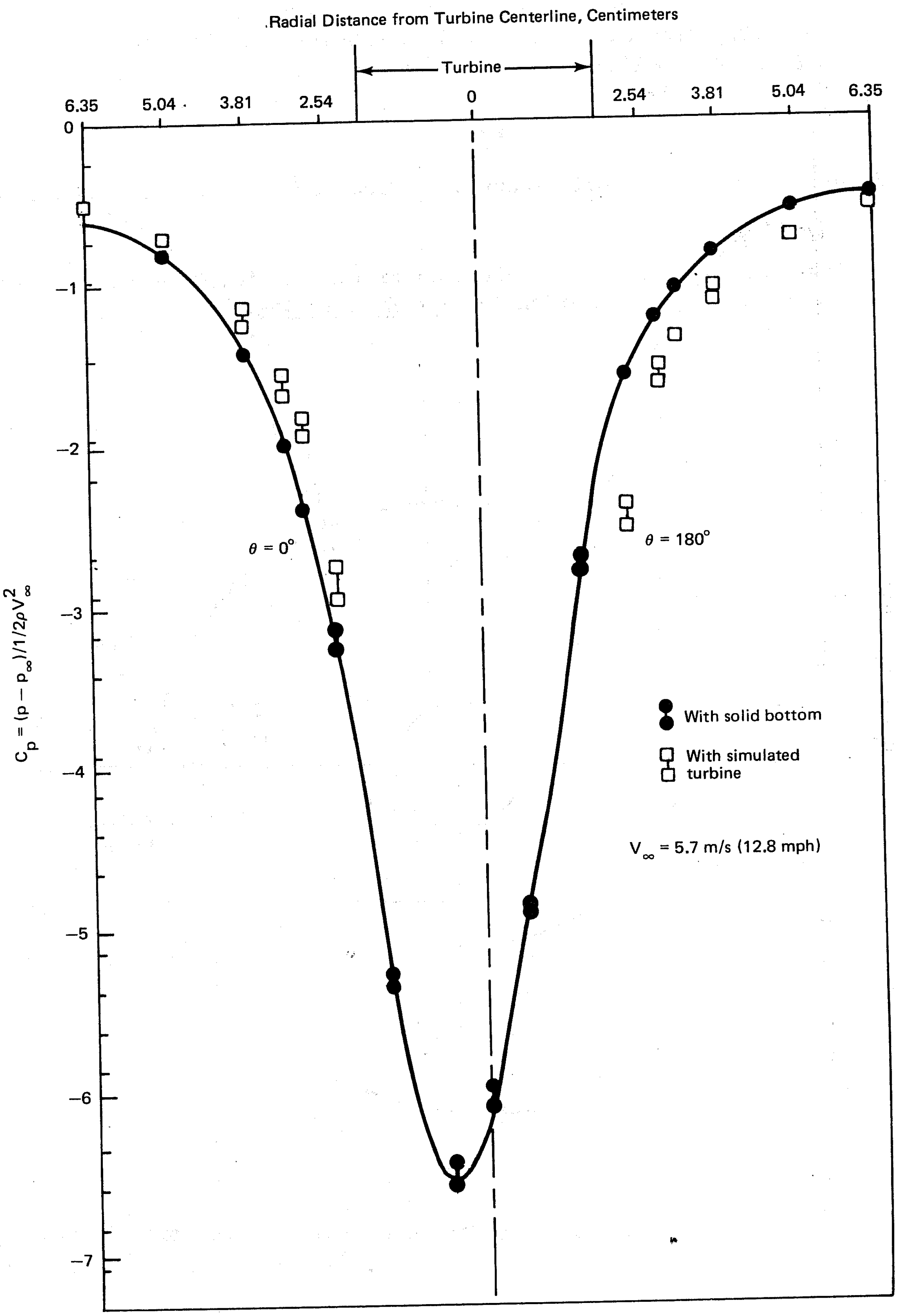


Fig. 3 Pressure Measurements on the Tower Bottom Wall With a Solid Plug or a 3.81 cm -diameter Screen-simulated Turbine (C_T = 4.77). Measurements are made along $\theta = 0°$ and 180° as defined in Fig. 2

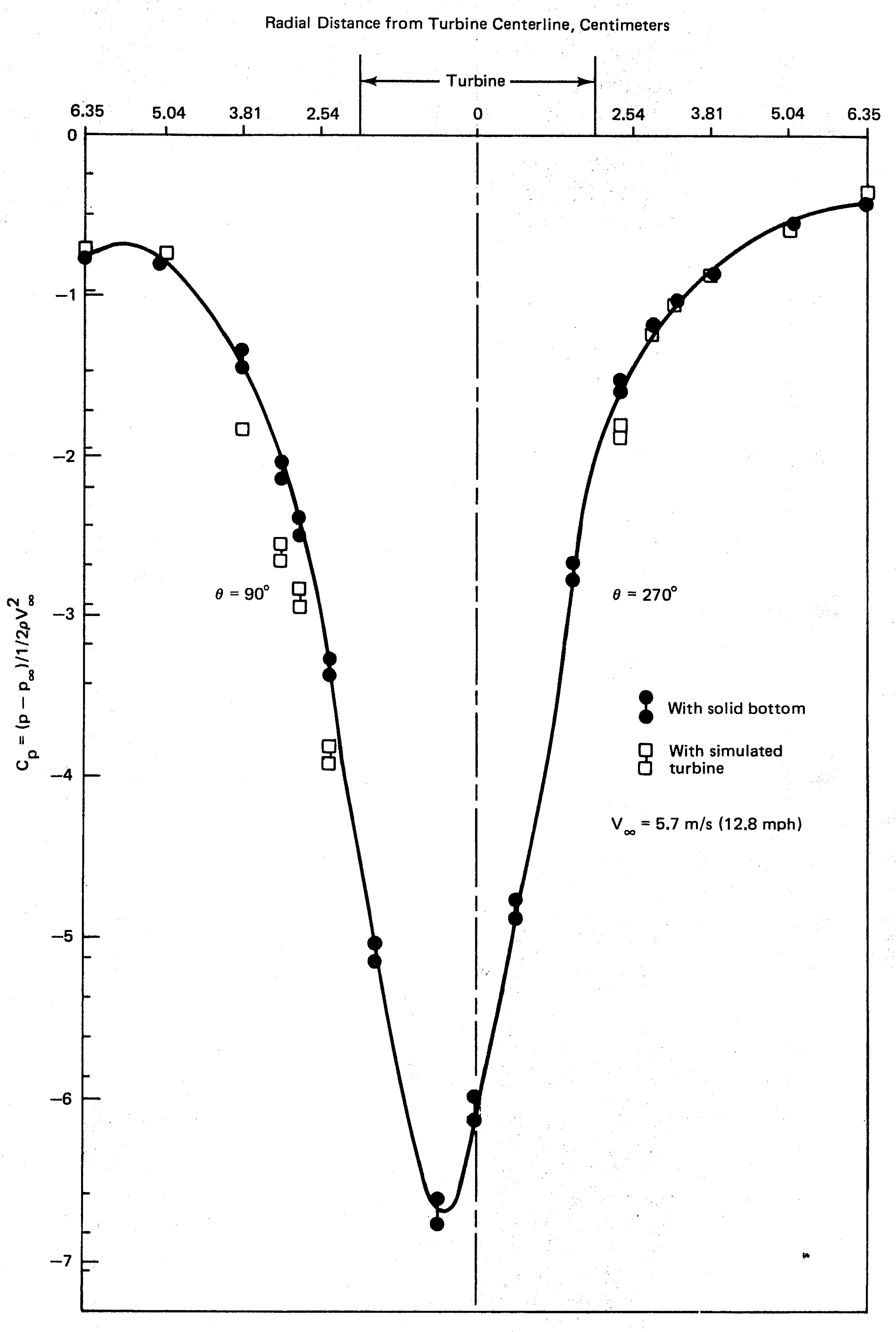


Fig. 4 Same as Fig.3 except θ = 90° and 270°.

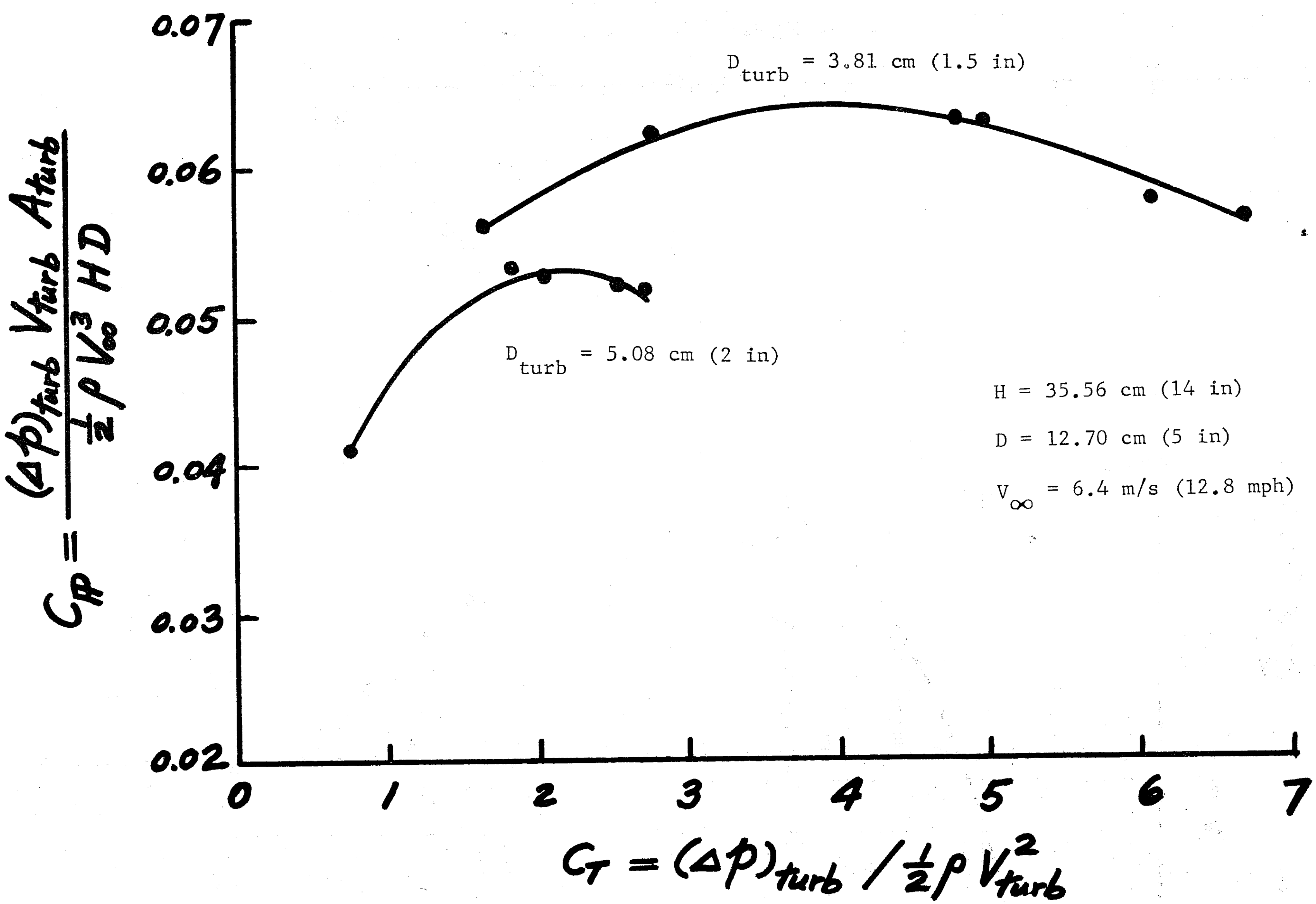


Fig. 5 Measured Power Coefficient Based on Tower Frontal Area as a Function of Turbine Disk Loading Coefficient

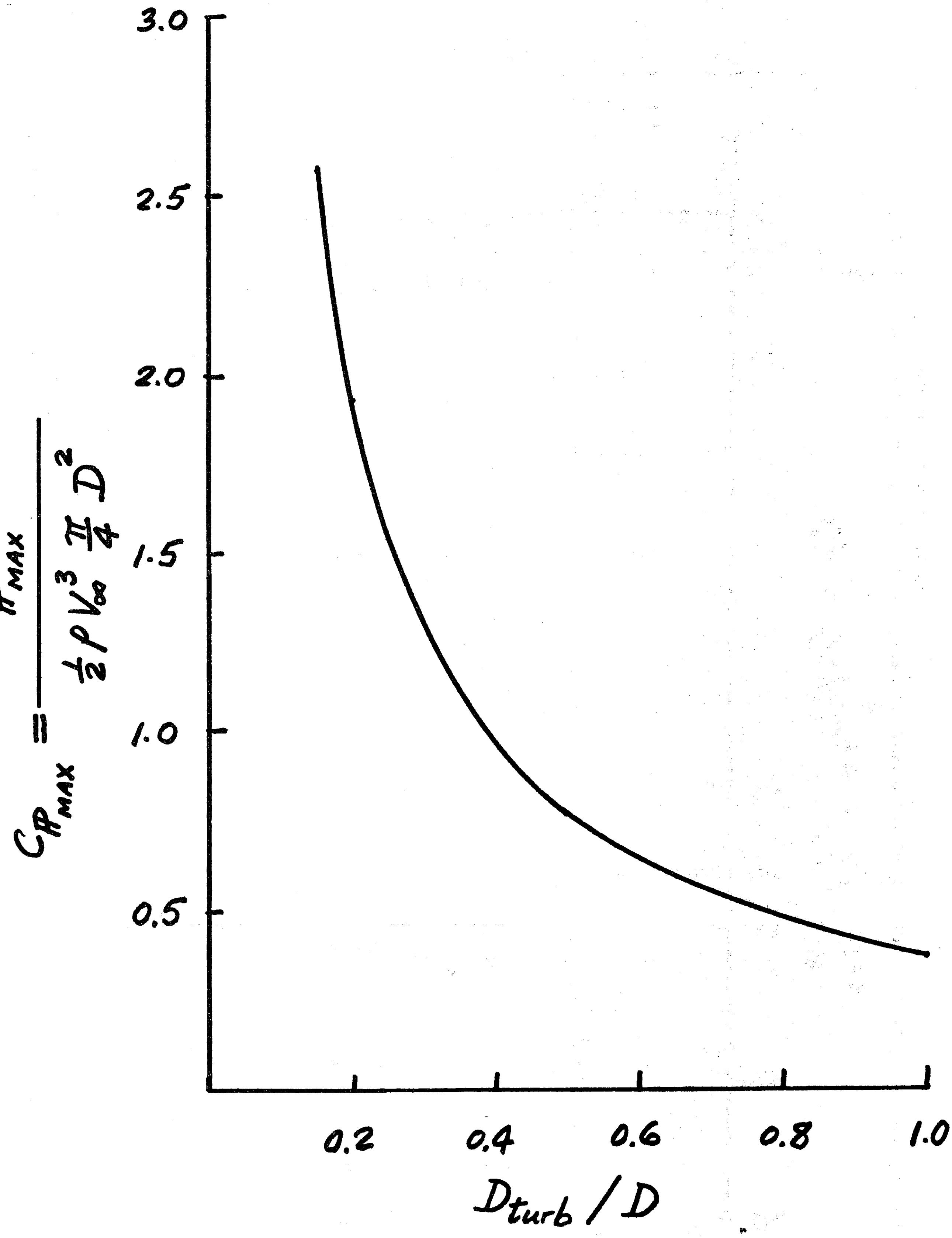


Fig. 6 Theoretical Maximum Power Coefficient Based on Tower Cross Sectional Area (From Refs. 2 and 3)

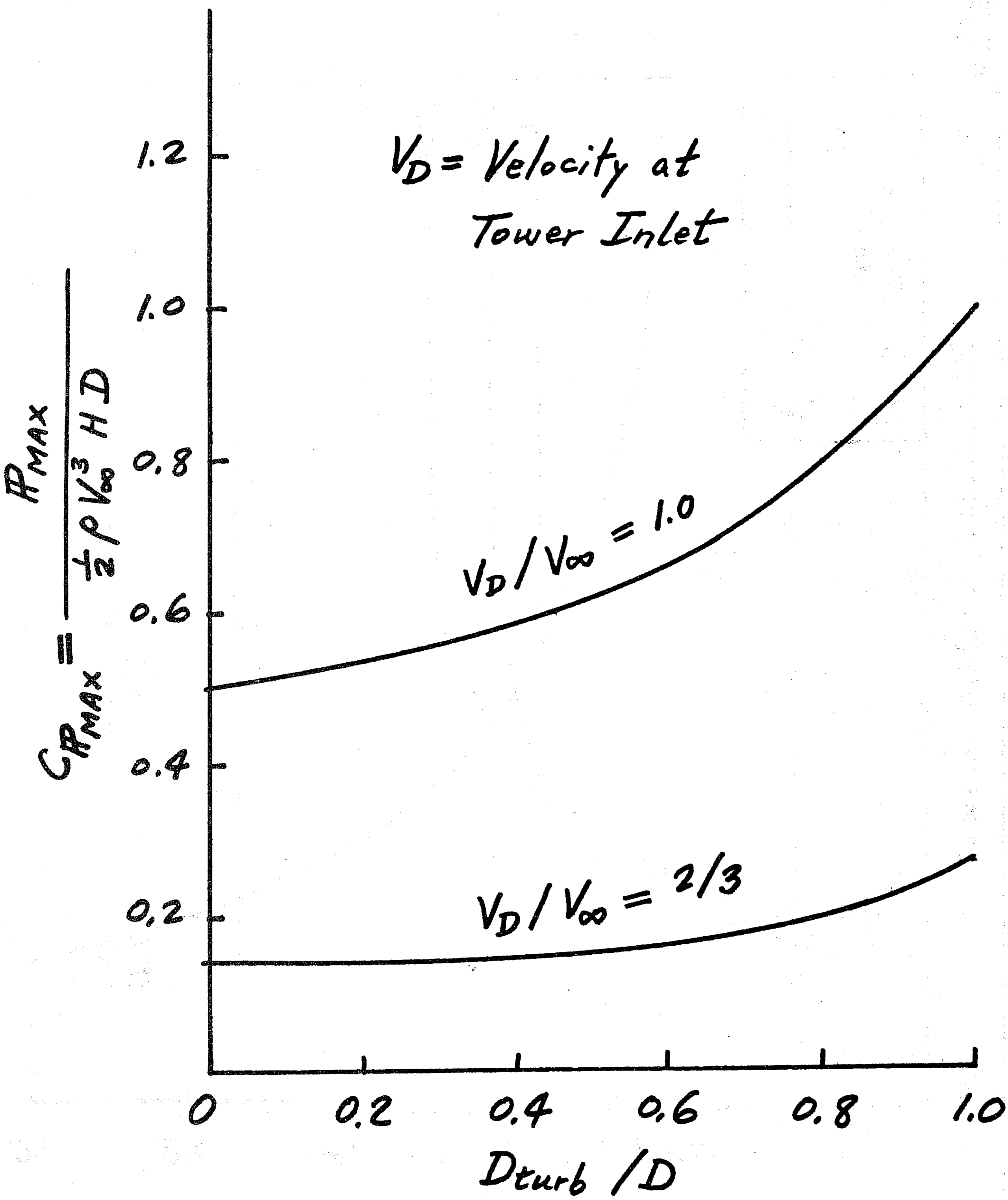


Fig. 7 Theoretical Maximum Power Coefficient Based on Tower Frontal Area (From Ref. 4)

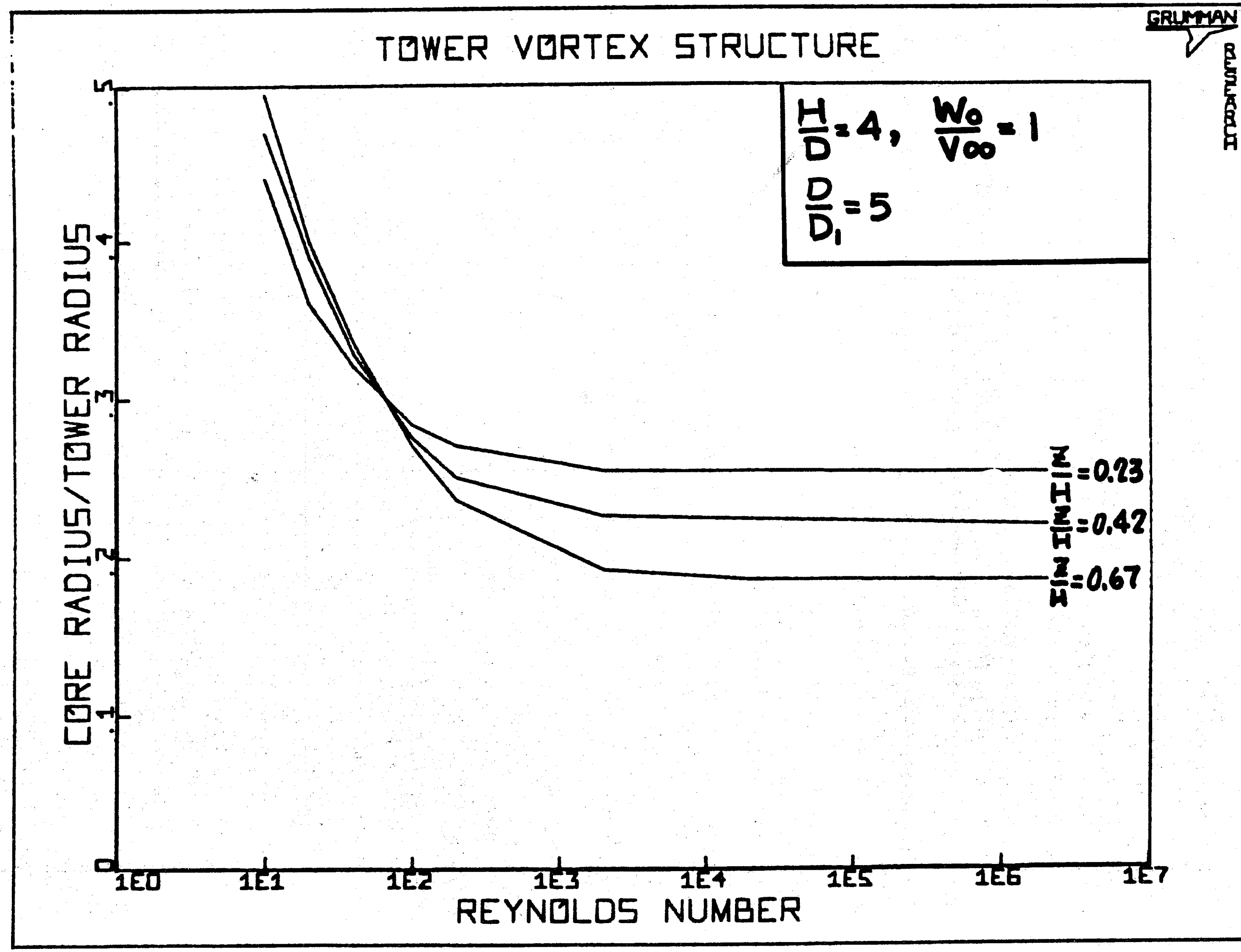


Fig. 8 Preliminary Theoretical Results on Core Radius Ratio as a Function of Tower Reynolds Number and Axial Location Z/H

DISCUSSION

Q. What would be the (C_P) power coefficient of the Tornado Wind Turbine based on the frontal area of the structure and not the turbine area?

YEN: This question has been answered in Figure 5.