CHAPTER 175

FLOW FIELD NEAR AN OCEAN THERMAL ENERGY CONVERSION PLANT

by

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The flow field in the vicinity of an Ocean Thermal Energy Conversion (OTEC) Plant is extremely complex. The plants will normally be located in an area of relatively high surface currents and the location must also be such that a large temperature difference exists between the lower layers and the surface. Locations that demonstrate this characteristic can in many cases be modeled as a two layer fluid as shown in Figure 1. A number of different designs for the OTEC plants are being considered, but they all have one thing in common, a large vertical cold water pipe. This pipe extends from near the surface to some point in the cold water layer (see Figure 1). In some designs this pipe is as large as 40 m in diameter and 460 m in length.

Having such a large object penetrating the interface between the two temperature layers in the presence of a shear flow can significantly alter the character of the interface. The highly turbulent wake downstream from the pipe can drastically effect the mixing across this density interface.

A conventional heat engine cycle is used in the plant with the high temperature source being the water in the upper layers and the low temperature reservoir being the water from the lower depths. Since the temperature difference is small for this type of plant (20° max.), vast quantities of both high and low temperature water must be used. The intake and discharge for the warm water as well as the cold water discharge will be in the upper layer; the intake for the cold water will be in the lower layer at or near the end of the cold water pipe.

The flow problem is thus one of a vertical cylinder in a two layer stratified shear flow with sources and sinks located along the cylinder.

Since the integrity of the temperature profile is of the upmost importance to the successful operation of the plant, an understanding of the flow field is essential. In addition, the possible alterations

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of the environment could be significant especially if a number of OTEC plants are located in the same area. This paper addresses itself to only part of this problem and even then only illustrates the need for more work. The part considered deals with the wake downstream from a cylinder in a two-layer stratified shear flow. A physical model of a typical cold water pipe was placed in a stratified flow facility and measurements were made just above the interface in the wake region.

The mixing across a density interface (thermocline) is believed to be a function of the turbulent energy present at or near the interface (Long). Although this subject is not completely understood at this time, the work of Long[1], Kato and Phillips[2] and others indicates that the erosion velocity U_e is proportional to U_1^3 where U_1 is the RMS of the turbulent velocity fluctuations near the interface. This relationship should hold provided the other parameters such as the density jump across the interface and the turbulent length scales remain constant. In the undisturbed ocean, the primary source of turbulence is the air-sea interaction at the surface. The intensity of the turbulence decreases with depth. This is perhaps the reason for the depth limits on the thermocline. The introduction of a source of turbulence at or near the thermocline can, as this paper shows, have a significant effect on the level of turbulent energy in this region.

It is difficult, if not impossible, to model all the significant dimensionless groups for a problem such as this. The groups that are of primary importance here are 1) interfacial Froude number, $\frac{\Delta V}{\sqrt{\frac{\Delta\rho}{\rho_2}gh}}$, 2) pipe diameter to interface thickness ratio, $\frac{D}{h}$, and 3) Reynolds number based on the pipe diameter, $\frac{VD}{\nu}$, where ΔV is the difference in the mean velocities between the upper and lower layers, $\Delta\rho$ the difference in mass density between the upper and lower layers, g the gravitational acceleration, h the thickness of the interface, ρ_2 the mass density of the lower layer, D the diameter of the pipe, V the velocity of the upper layer and ν the kinematic viscosity of the water. The first two groups were held constant for the model and prototype, but this was not possible in the case of Reynolds number. In fact, the Reynolds numbers for the prototype and model were quite different, approximately 10^6 for the prototype and approximately 10 for the model. This must be kept in mind when drawing conclusions about the prototype from the experimental results.

The experiments were performed in a stratified flow facility 24.5 m long, 1.22 m high and .61 m wide (for a complete discription of the facility see Ref. 3). Sodium chloride was used as the stratifying agent for these experiments. The lower .61 m of the tank was filled with salt water (dyed red to aid in the flow visualization) and the upper .61 m filled with fresh water. Specific gravity and Brunt Väisälä frequency profiles are shown in Figures 2 and 3. A pump in the 30 cm diameter pipe connecting the ends of the tank is used to circulate the upper layer and create the shear flow velocity profile shown in Figure 4. Salt water was continuously added at the bottom of the tank and fresh water drawn from the top during the experiments to maintain the interface at approximately the same location. A crosswire hot film probe for measuring y and z components of the velocity and velocity fluctuations, a high resolution electrical conductivity probe for measuring mass density and a glass beaded thermistor for measuring temperature. Were attached to a vertically and horizontally traversing probe support. The four transducer outputs plus a signal giving the location of the probes were digitized and recorded on magnetic tape. The data was reduced on an IBM 370 Mod 65 computer.

The experimental procedure was as follows: The pump was started and allowed to run for approximately one and one-half hours so that the flow could reach an equilibrium condition. A constant speed vertical traverse was made to obtain a mass density profile and locate the position of the interface. A stepped vertical traverse was than made to obtain a time averaged velocity profile. Next the probes were placed approximately 1 cm above the interface and turbulence measurements were made. The cylinder was then put in place and turbulence data taken at the positions shown in the definition sketch.

Constant speed traverse were also made during and at the completion of the turbulence measurements to precisely locate the interface.

The results are given in Table 1 and Figures 5-9. The erosion velocity (velocity at which the interface recedes) is believed to vary as the cube of the RMS velocity near the interface[1]. Figure 5 is a graph of the ratio of the erosion velocity with the cylinder to the erosion velocity without the cylinder at the cross sections of the wake shown in Figure 1.

Although more data points are needed to obtain a complete picture the results clearly indicate a substantial increase in the turbulent energy present at the interface. The vastly increased mixing was visible to the eye and was recorded on movie film (shown at conference). Energy density spectra for the horizontal and vertical components of velocity are shown both without (Figures 6 and 7) and with (Figures 8 and 9) the cylinders. Note the overall higher turbulent energy level in the wake. The vortex sheading frequency is also clearly visible in Figures 8 and 9. It should be pointed out again that the Reynolds number based on the pipe diameter for the model is much lower than for the prototype. At higher Reynolds numbers, however, the turbulent energy will undoubtedly be higher and thus the mixing in the wake of the prototype would be ever greater.

No attempts to integrate the erosion velocity over the wake region was made since with the large difference in Reynolds numbers the results cannot be directly applied to the prototype. The results do however indicate that this problem should be investigated further.

REFERENCES

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2. Long, R.R., "The Influence of Shear on Mixing Across Density Interfaces," J. Fluid Mech., Vol. 70, Part 2, pp. 305-320, 1975.

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Point No.	X (cm)	Y (cm)	ξ (cm)	$\overline{u}$	RMS u	RMS v	$\sqrt{\overline{uu} + \overline{vv}}$	$\frac{UeTube}{Ue}$	NOTES
1	0.75	12.38	0.83	--	--	--	--	--	Velocity too small
2	2.02	12.38	0.88	2.132	0.489	0.271	.560	20.9	With Tube
3	3.29	12.38	0.98	2.23	0.332	0.129	.356	5.39	With Tube
4	4.56	12.38	0.93	2.26	0.187	0.052	.194	0.873	With Tube
5	0.75	26.19	1.08	2.23	0.301	0.190	.356	5.39	With Tube
6	2.65	26.19	1.12	2.46	0.328	0.178	.374	6.25	With Tube
7	4.56	26.19	1.21	2.48	0.203	0.095	.224	1.34	With Tube
8	5.83	26.19	1.16	2.39	0.208	0.055	.215	1.19	With Tube
9	0.75	40.00	1.27	2.37	0.256	0.133	.289	2.88	With Tube
10	2.65	40.00	1.30	2.45	0.241	0.140	.279	2.60	With Tube
11	4.56	40.00	1.32	2.47	0.247	0.106	.268	2.30	With Tube
12	7.10	40.00	1.35	2.47	0.207	0.054	.214	1.17	With Tube
13	0.75	65.56	1.39	2.31	0.163	0.078	.180	0.67	With Tube
14	2.65	65.56	1.41	2.31	0.202	0.087	.220	1.27	With Tube
15	5.83	65.56	1.44	2.35	0.168	0.068	.182	0.72	With Tube
16	8.37	65.56	1.46	2.34	0.147	0.047	.154	0.44	With Tube
--	0.75	16.98	0.72	2.895	0.220	0.035	.223	--	Without Tube
--	0.75	16.98	1.74	3.256	0.175	0.054	.183	--	Without Tube

Diameter of Tube = 1.9 cm

$\Delta\rho$ = 0.024 grams/cm^3

ρ_2 = 1.024 grams/cm^3

Table 1

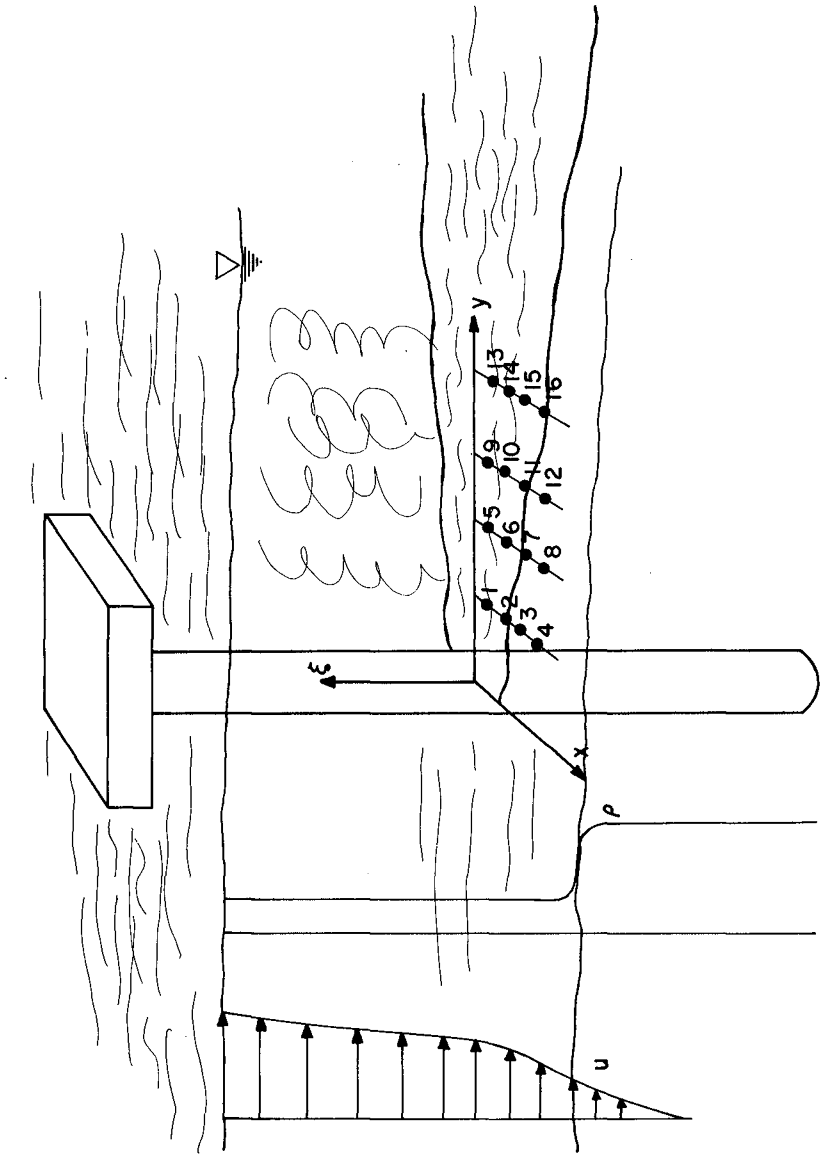

Figure 1 Definition Sketch.

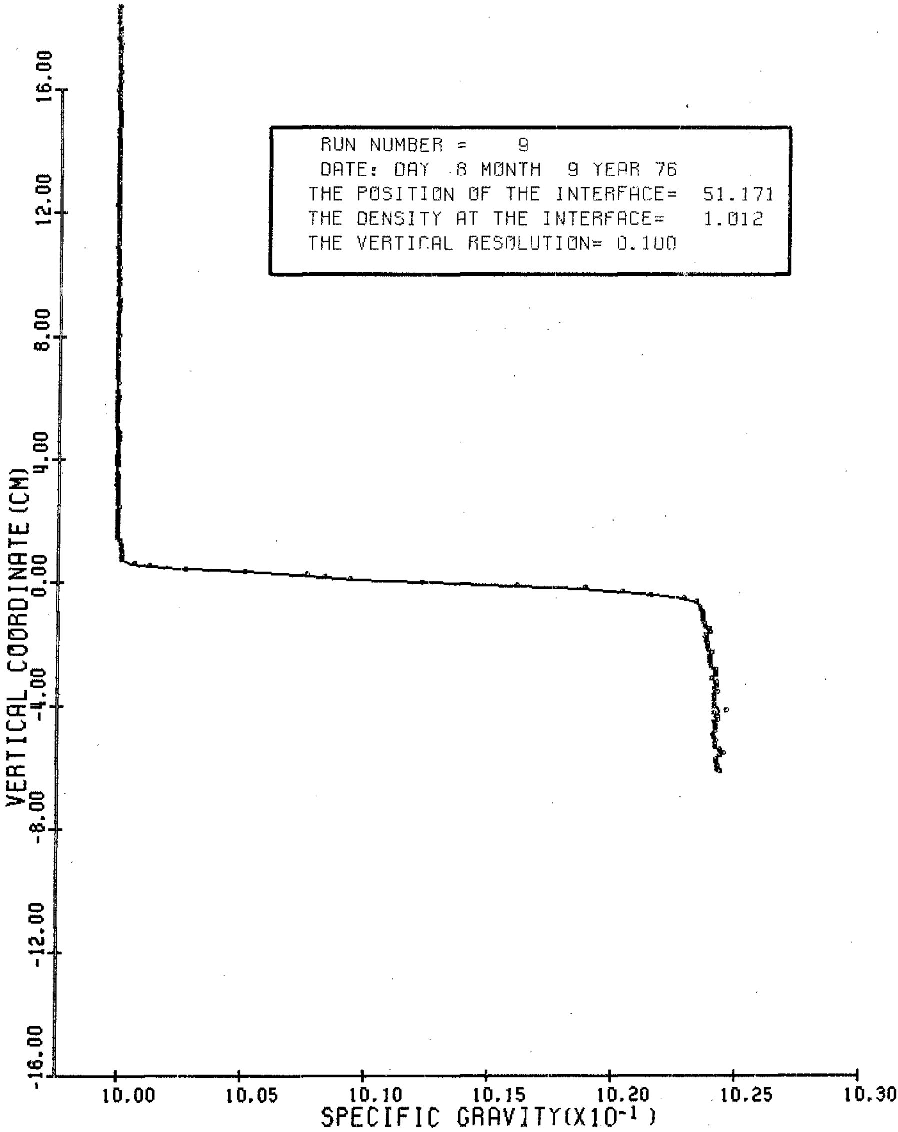

Figure 2 Specific Gravity Profile.

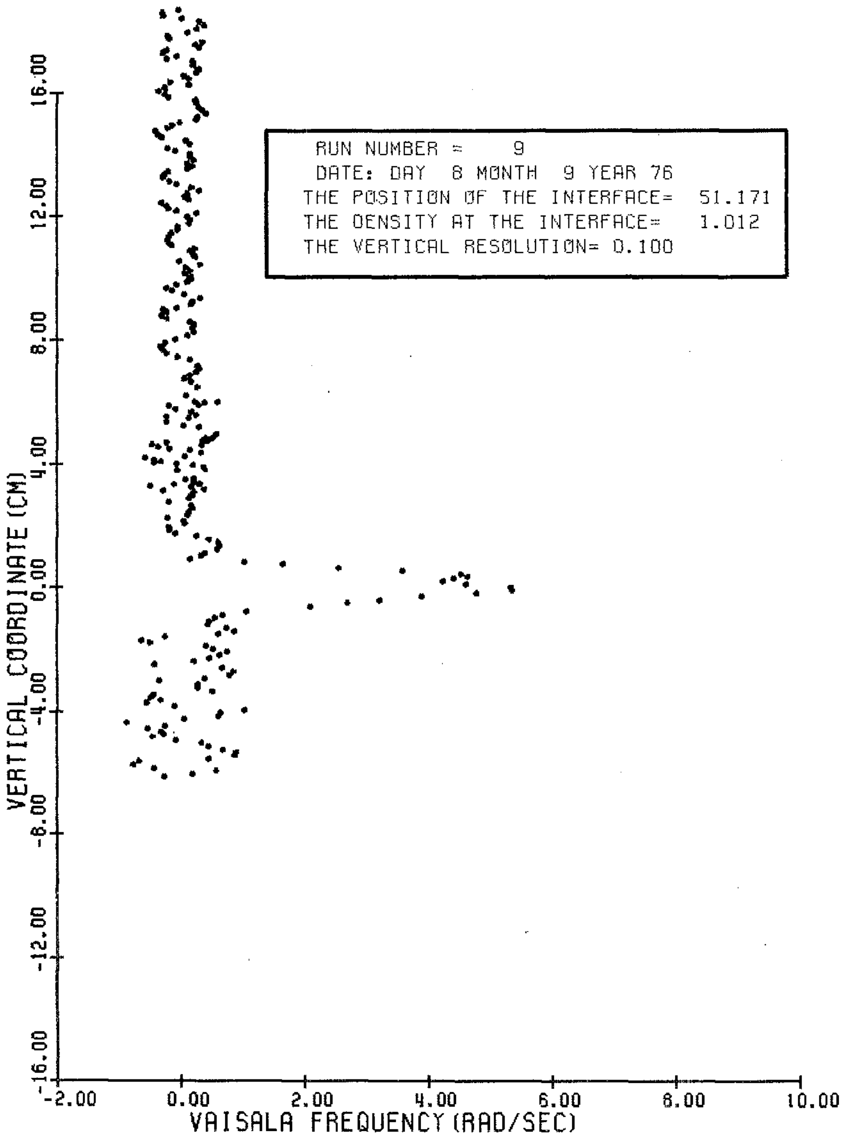

Figure 3 Väisälä Frequency Profile.

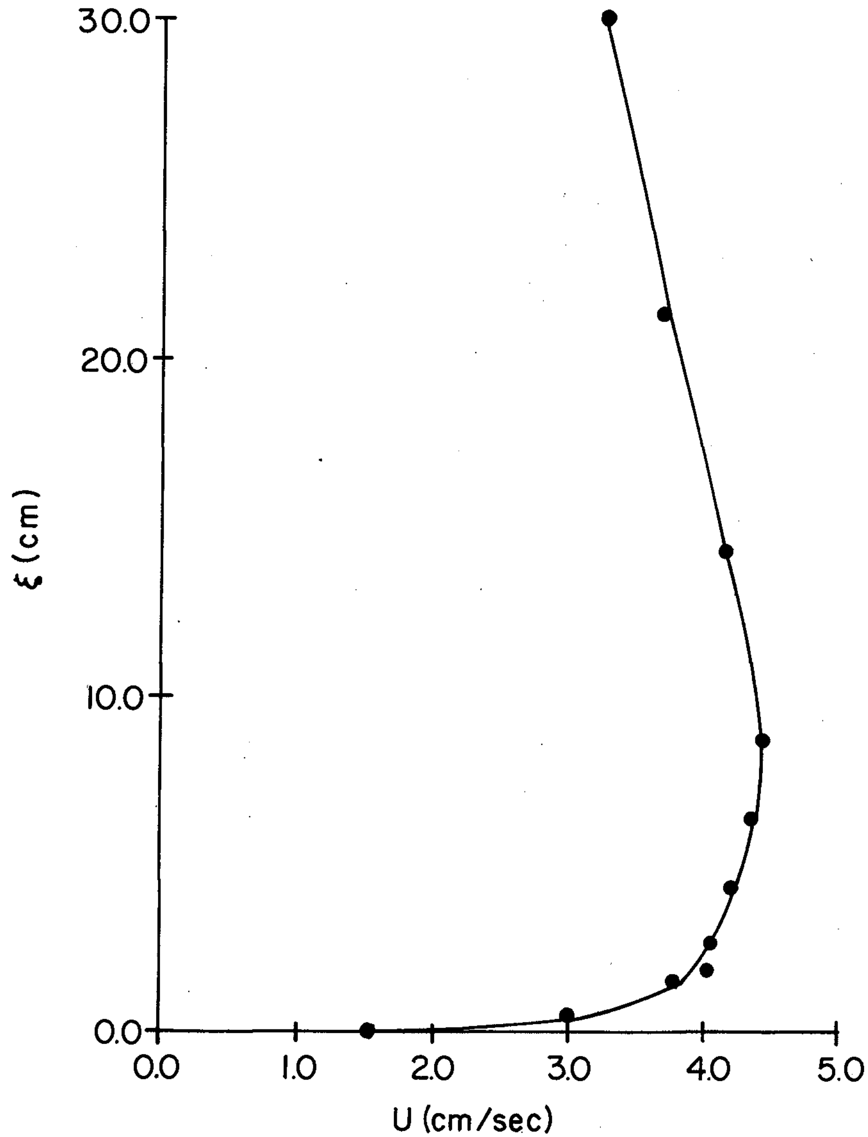

Figure 4 Mean Velocity Profile.

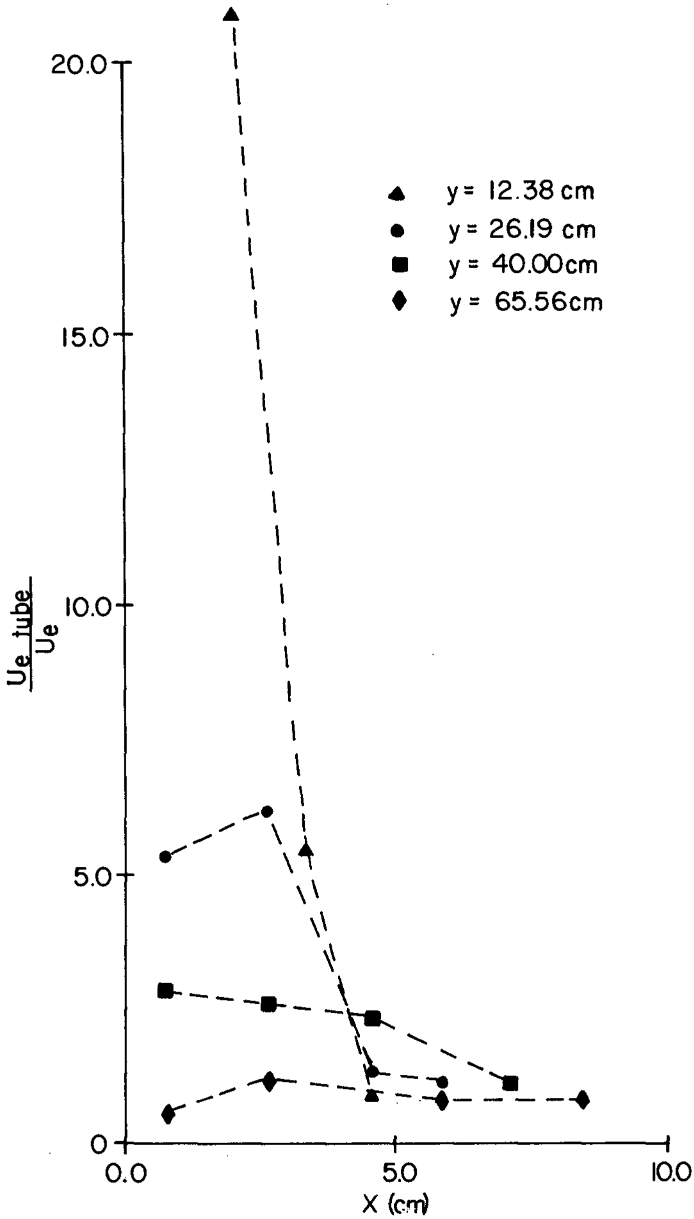

Figure 5 Erosion Rate Ratio.

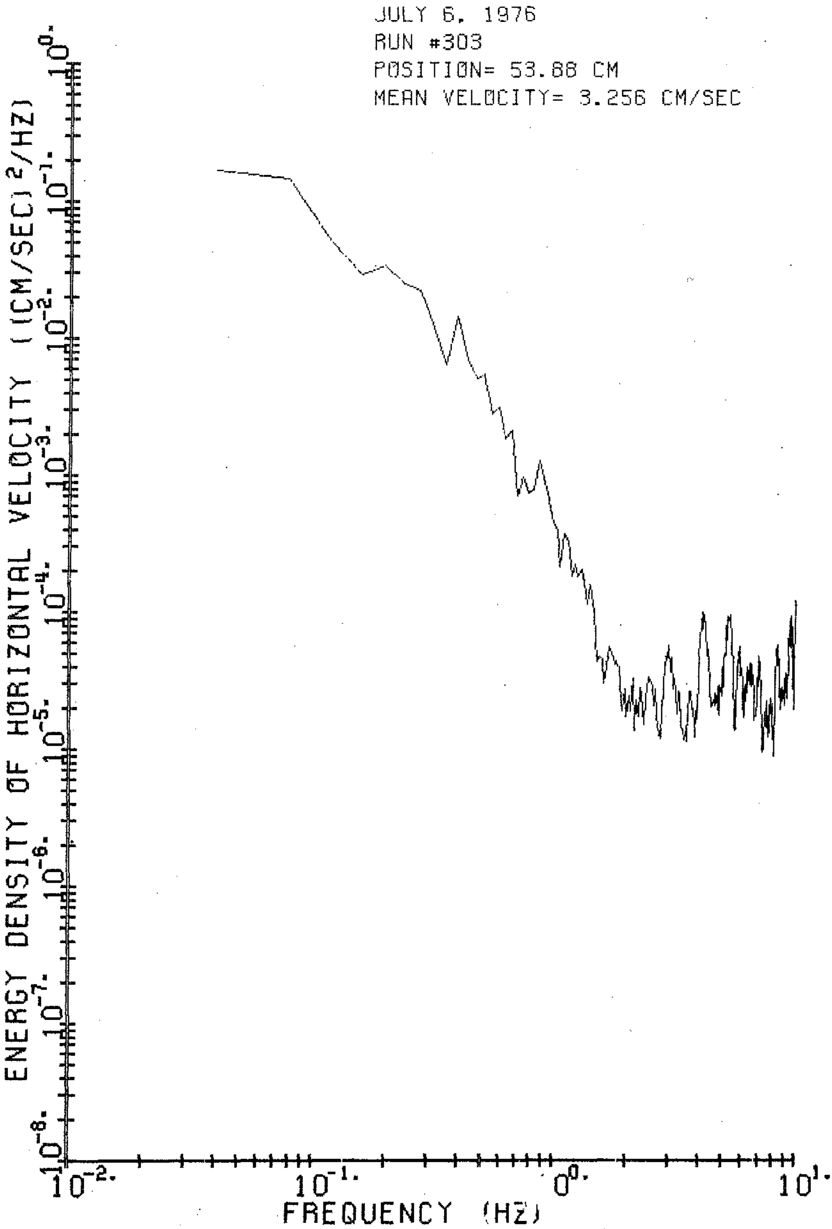

Figure 6 Energy Density without Cylinder.

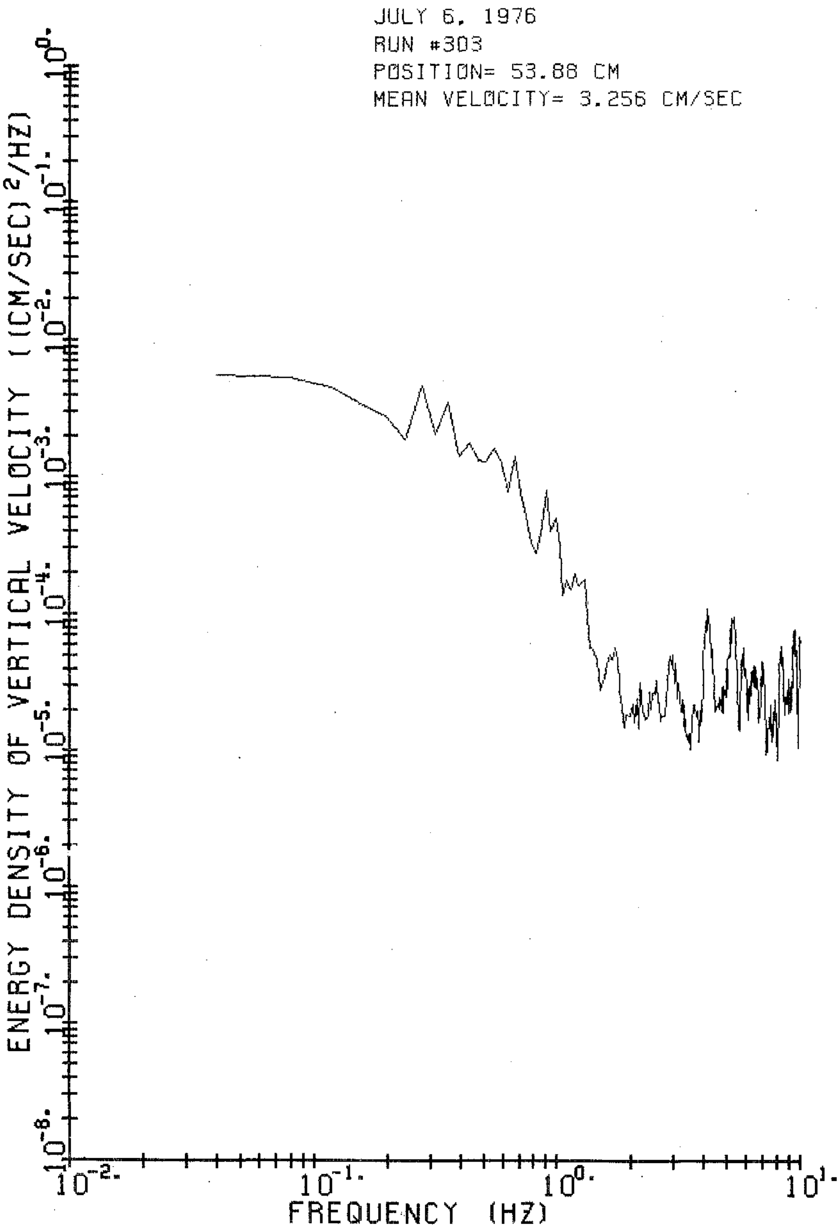

Figure 7 Energy Density without Cylinder.

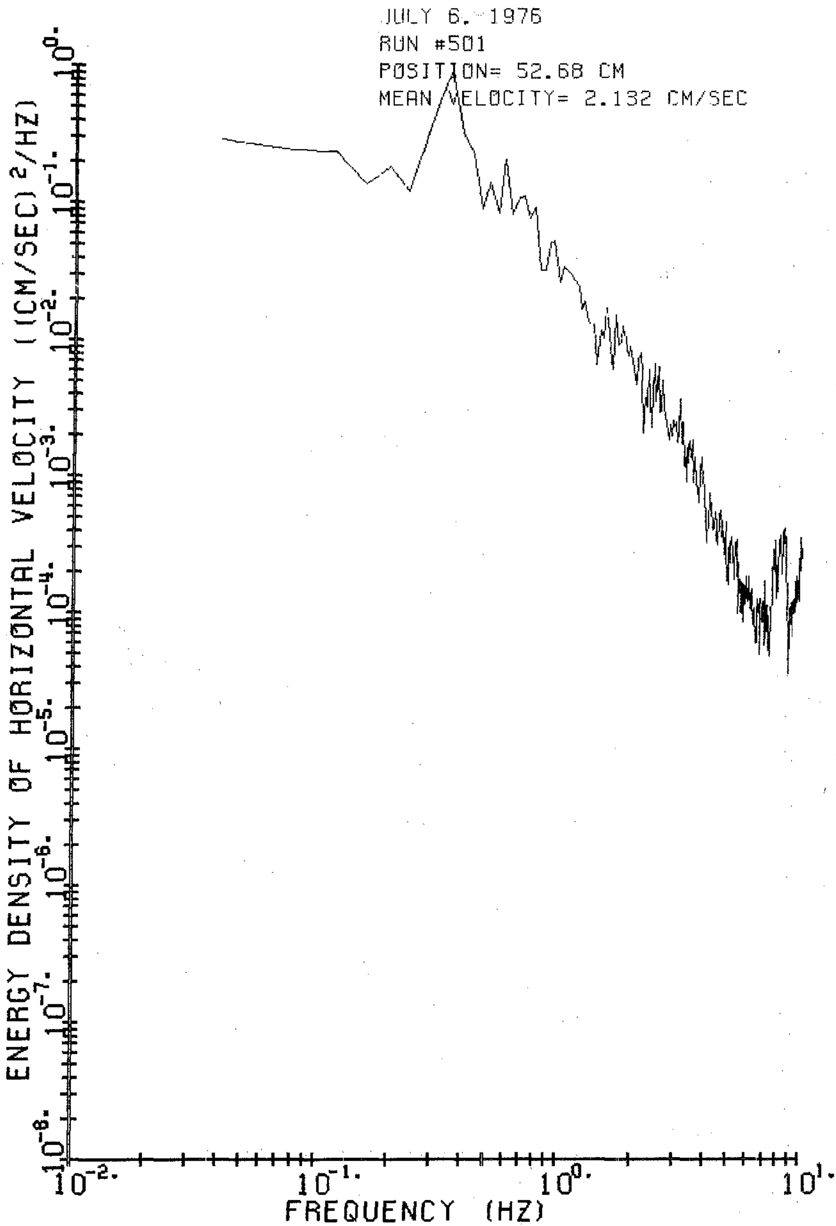

Figure 8 Energy Density with Cylinder.

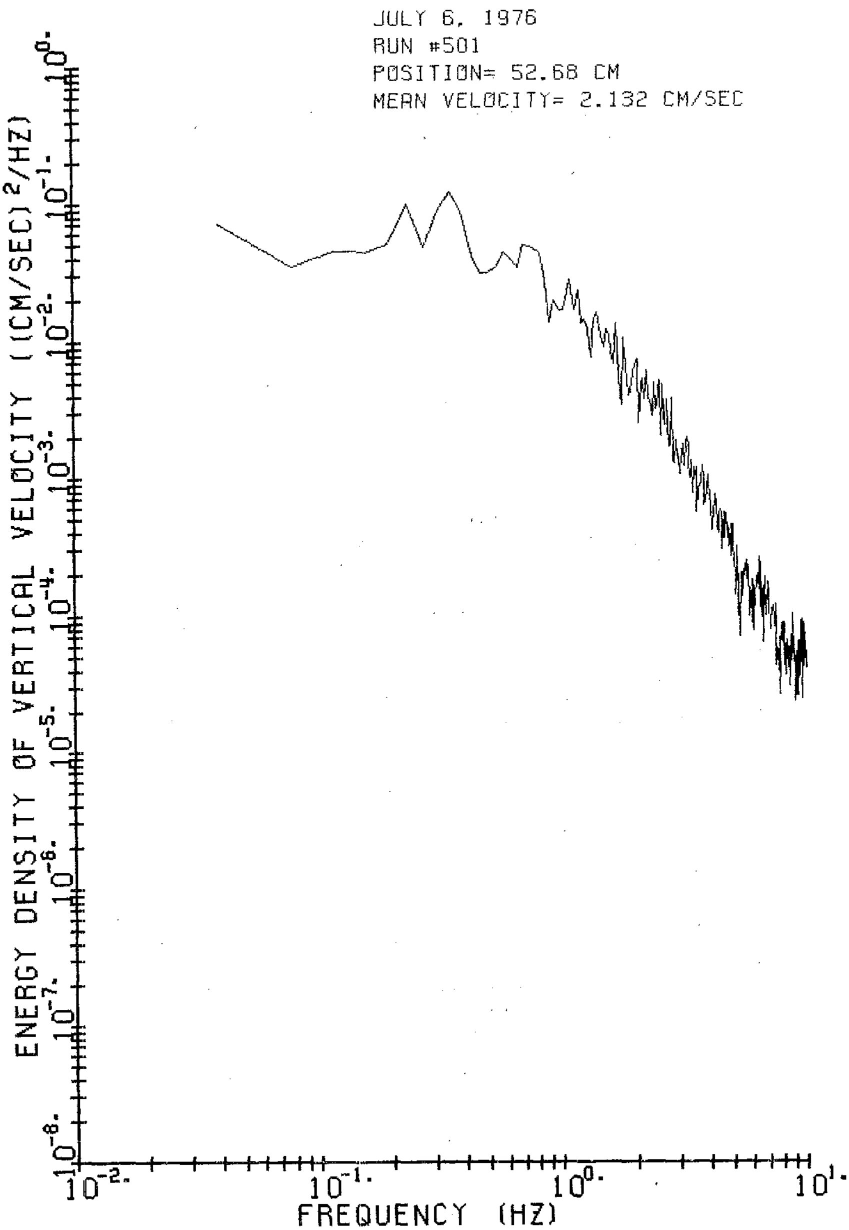

Figure 9 Energy Density with Cylinder.