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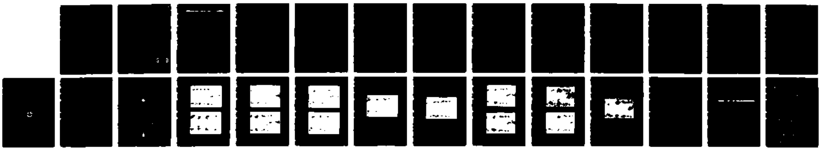

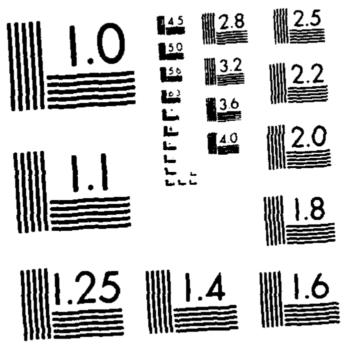
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David Taylor Research Center

Bethesda, MD 20084-5000

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Ship Hydromechanics Department

PROPELLER WAKE FLOW VISUALIZATION NEAR A FREE SURFACE

by

SCOTT FISH

JAMES N. BLANTON

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FIGURES

NOTATION

D	Propeller diameter
J	Advance ratio = $U_{carr}D/n$
n	Propeller rpm
R	Propeller radius
U_{carr}	Carriage velocity
x	Streamwise distance from plane of propeller blade midchords
z_{hub}	Depth of hub axis from free surface
Γ	Vortex strength

ABSTRACT

Propeller wake flow visualization was carried out for several depths of submergence below a free surface. The wake was visualized by laser light sheet illumination of the blade tip vortex helix seeded with fluorescein dye. Instability in the helix was apparent at much shorter distances downstream than has previously been observed in cavitation experiments. Effects of the free surface on the propeller wake were seen at the shallower submergence depths. Select video frames are presented with preliminary comments. A more complete analysis will follow in a later report.

ADMINISTRATIVE INFORMATION

The work described in this report is part of the Surface Ship Wake Consortium sponsored by the Office of Naval Research (ONR) Applied Research Program, under Program Element 61153N, Task Area BT02301N1, and performed under the David Taylor Research Center (DTRC) work unit 1-1504-200 (FY 88).

INTRODUCTION

Recent interest in propeller wake interaction with the free surface has grown from concerns over the causes and control of ship hydrodynamic signatures. This interest has led to investigations of the wake of propellers currently being conducted by several organizations. Measurements made at David Taylor Research Center (DTRC) have shown a lack of blade rate periodicity in velocity by five propeller diameters downstream (Blanton and Fish, 1988). This degradation of blade rate dependance suggests either turbulent diffusion of the individual blade wakes or a modification in flow geometry disturbing the wake axisymmetry. Photographs of propellers cavitating in water tunnels however show very symmetric helical structure in the propeller wake (It should be noted that typical cavitation tunnels prohibit wake examination beyond $x/D=2.0$) (Kuiper, 1979). In order to examine the interaction of the propeller wake with a free surface, the structure of the wake should be identified and understood. This understanding is of fundamental importance in validating numerical prediction codes aimed at simulating the propeller wake interaction with the free surface. Due to the complicated nature of this flow field, a visual perspective on the wake evolution was deemed necessary prior to any detailed wake survey measurements. This report serves as a preliminary review of flow visualization data collected on a propeller wake operating at two depths below a free surface. Several photographs showing laser light sheet illumination of the tip vortex helical wake are given with brief comments. A more detailed analysis of video recordings of the wake will follow in a later report.

A brief description of the experiment is given in the next section followed by the photographs and comments. Discussion of the primary feature in the photographs (an apparent instability in the helical tip vortex wake) is then followed by suggestions for further investigation of the phenomena.

EXPERIMENTAL TECHNIQUES

The David Taylor Research Center 140 foot Towing Basin was used for experiments presented in this report. The carriage was operated at speeds from 1 to 4 ft/sec. All of the data presented here were taken at a carriage speed of 1 ft/sec due to maximum dye clarity.

A four bladed, 12 inch diameter propeller (DTRC #3563) was used. This propeller was modified by milling a 1/8 inch wide slot in each blade face for dye delivery to the blade tip from the hub as shown in Figure 1.

A tri-strut and pod configuration was designed and built to minimize both the free surface disturbance and the propeller inflow asymmetry while maintaining structural rigidity (see Figure 2). The propeller drive motor was remotely located on the carriage and was connected to the hollow prop shaft through an inclined 3/8 inch shaft positioned just forward of the center strut. A variable speed positive displacement pump was used to supply a fluorescein dye solution to the pod. Dye pump rates were varied around a minimum flow rate necessary for visualization. No apparent effect on the vortical flow-field was noticed.

A laser light sheet, positioned as shown in Figure 3, was used to excite the fluorescein dye. The light sheet was created using a 110 mW argon-ion laser directed into a 30 Hz vibrating mirror. This sheet was fixed (not moving with the carriage) in the vertical plane and aligned with the propeller axis.

A Sony 3/4 inch, 30 frame per second video tape recorder was used to record images from a high sensitivity black and white camera mounted on the basin side as shown in Figure 3. The images shown here are 35 mm photographs of the video screen.

PRESENTATION OF RESULTS

DEEP SUBMERGENCE

Figures 4a and b show the propeller moving from left to right and operating at a depth of $z_{hub}/R=2.0$, and $J=0.8$. Although the free surface is just out of view at the top of the photograph, a qualitative comparison of the size and trajectories of the upper versus lower vortex sets suggests the free surface is having a small effect on the propeller wake helix. Figure 4b was taken 2.63 seconds after Figure 4a and the center of the screen corresponds to an $x/D=3.3$. At this point in the wake the vortex cores shown in figure 4a have merged as pairs. This is shown by the four large vortical structures of Figure 4b compared to the seven smaller of Figure 4a (eight will be visible as the propeller moves out of view). By $x/D=6.0$ the dye spots quickly transition to a turbulent state signaling the instability of the vortex structure possibly through vortex breakdown.

Figures 5a–e are a screen sequence taken 0.1 second apart showing the vortex interaction in the helical wake for a higher rpm corresponding to $J=0.5$. Substantial deformation of the wake helix beginning with the movement of two vortices towards and around each other occurs at $x/D=0.4$. By following the vortex cores marked "1" and "2" in this sequence, one can determine the axial distance of $x/D=0.95$ (in Figure 5d) where a vortex pair has become vertically aligned. Velocities approximated by tracking these vortices can be used to estimate the vortex strength at $\Gamma=6.0$ ft^2/sec. In contrast to the $J=0.8$ case shown previously, the vortex pairs do not merge. Rather the inside vortex is convected further downstream to interact with another vortex. This convection phenomenon is magnified at higher propeller loadings due to the increase in velocity gradient at the edge of the propeller jet where the vortices interact.

SHALLOW DEPTH

Figure 6 shows the propeller at $z_{hub}/R=1.25$ and $J=0.8$. Comparison of Figure 6 with Figure 4a indicates very little difference in the lower set of vortices. It appears, however, that the dye diffusion rate in the upper set of vortices is increased for the shallow depth case.

Figure 7a–e show a frame sequence for higher rpm corresponding to $J=0.5$. These frames are also spaced in time at 0.1 second intervals. Again the vortices interact in the same manner as shown at the deeper depth of Figure 5. Preliminary measurements from the video screen show little change in the vortex trajectories from those at deeper depths. The dye diffusion rate in the upper vortices does appear to increase slightly at the shallower submergence depth.

WAKE PERSISTENCE

The authors also noticed large turbulent structures occurring intermittently in the wake long after the propeller had passed and most of the turbulent motion had diffused to low intensity. The propeller wake also migrated slowly towards the free surface. Once wake contact has been made with the free surface, however, higher momentum fluid quickly migrated upward forming strong surface currents. These surface currents were visible through movement of dust particles on the surface in the light sheet. Further details on these observations will be given in a full report.

DISCUSSION AND RECOMMENDATIONS

The experiment described here included video recording of a complete range of propeller loadings, and carriage speeds. In addition, limited video coverage of the 3-Dimensional form of the helix, was also obtained. Only a very select few of the cases are shown here for a initial presentation of the results. A complete analysis will follow.

In the near term, however, some comments and recommendations can be made based on the data collected. First, the existence of an instability in the propeller wake helix is clearly shown by this experiment. Widnall (1972) has shown analytically three modes of helical vortex filament instability. Lugt

(1962) has also given evidence of the high sensitivity of helical vortex flows to small perturbations in axisymmetry. The nature of perturbations in this experiment and their possible effects on the helical wake are currently under investigation and will be reported later. Some care should be exercised in the interpretation of the flow visualization results until this perturbation analysis has been completed.

The implications of the wake helix instability may have a significant effect on current numerical design and prediction methods for propellers. These codes assume stable helical wakes in their calculations (Greeley and Kerwin, 1982). Greeley and Kerwin have also shown the sensitivity of computed results on the propeller wake geometry. Incorporation of an instability analysis in these calculations, however, should be pursued with great caution. An understanding of the physical links between various types of perturbations representative of both model testing and full scale operation should be evaluated to supply representative boundary conditions to numerical codes.

The authors recommend that an analytical investigation of perturbation sources and their effects on propeller wakes be carried out with verification and guidance provided by the experimental apparatus described herein. This plan embodies a timely and cost effective method for developing the necessary understanding of propeller wake instability. The experimental apparatus provides a standard platform for propeller wake measurement and possesses the flexibility to investigate perturbations of many types at low operational cost. In addition, the flow visualization system can be used to locate specific areas of interest for quantitative measurement.

ACKNOWLEDGEMENTS

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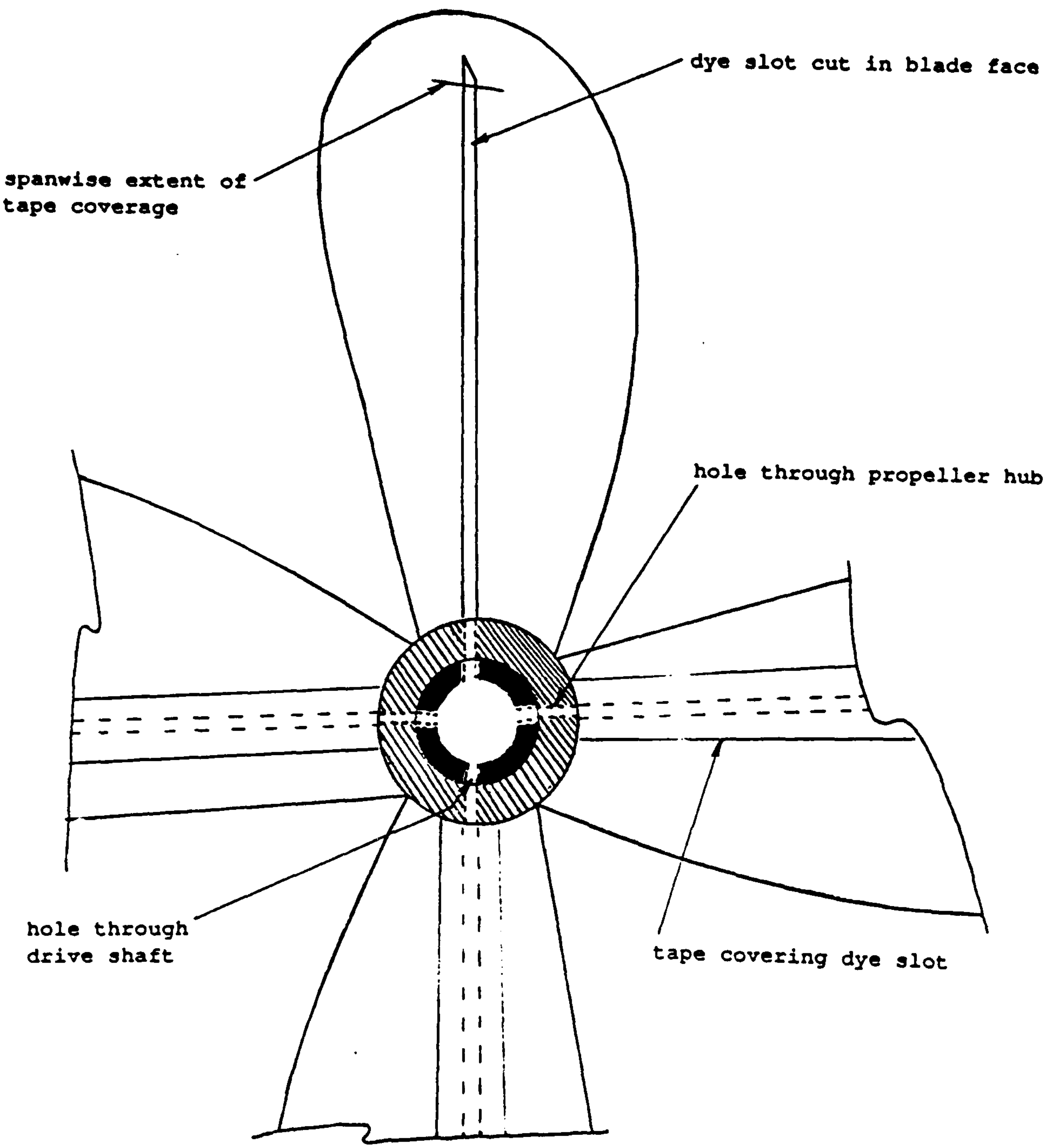


Figure 1. Four bladed propeller with hollow hub and dye slotted blades

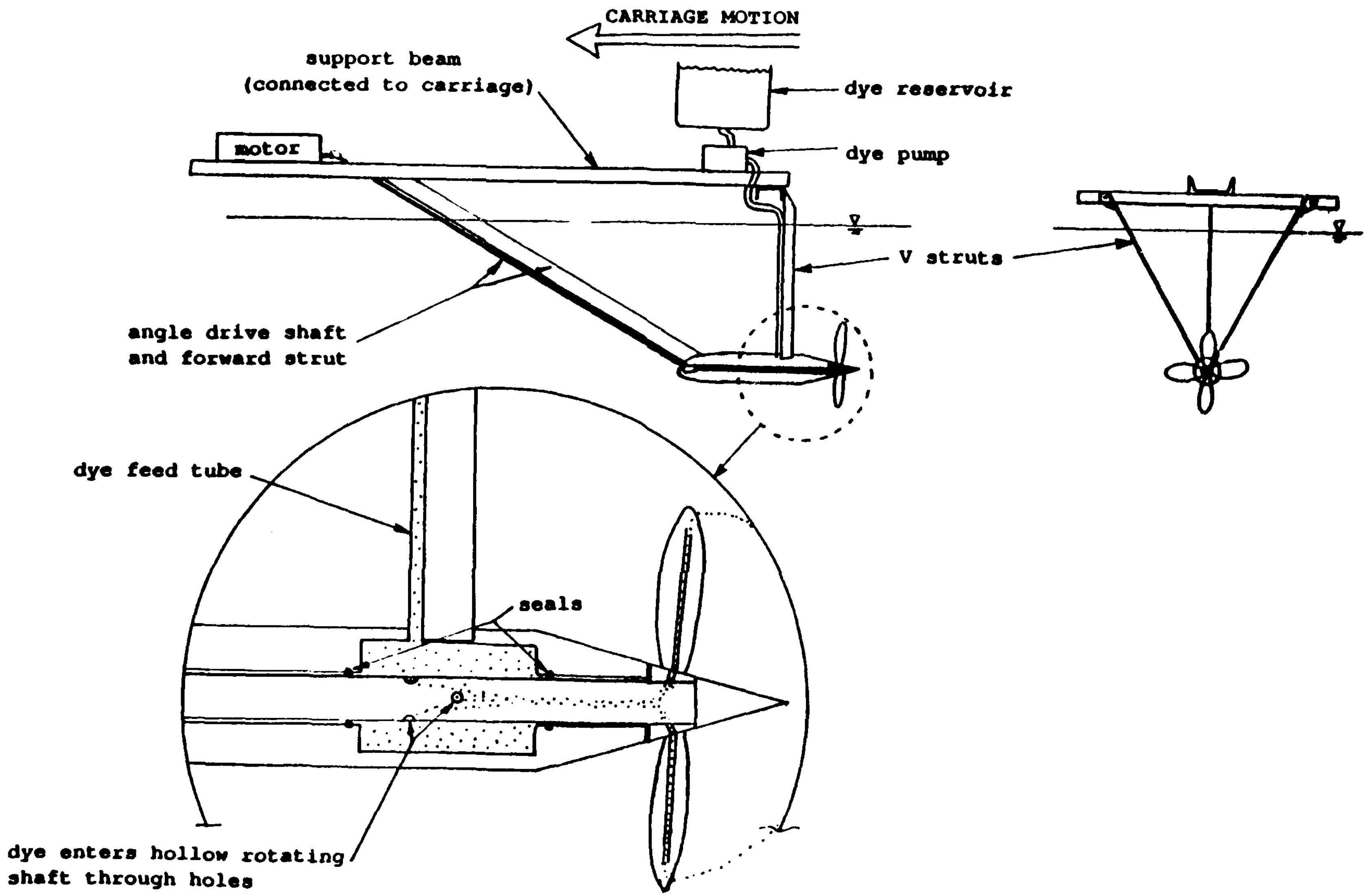


Figure 2. Experimental Configuration

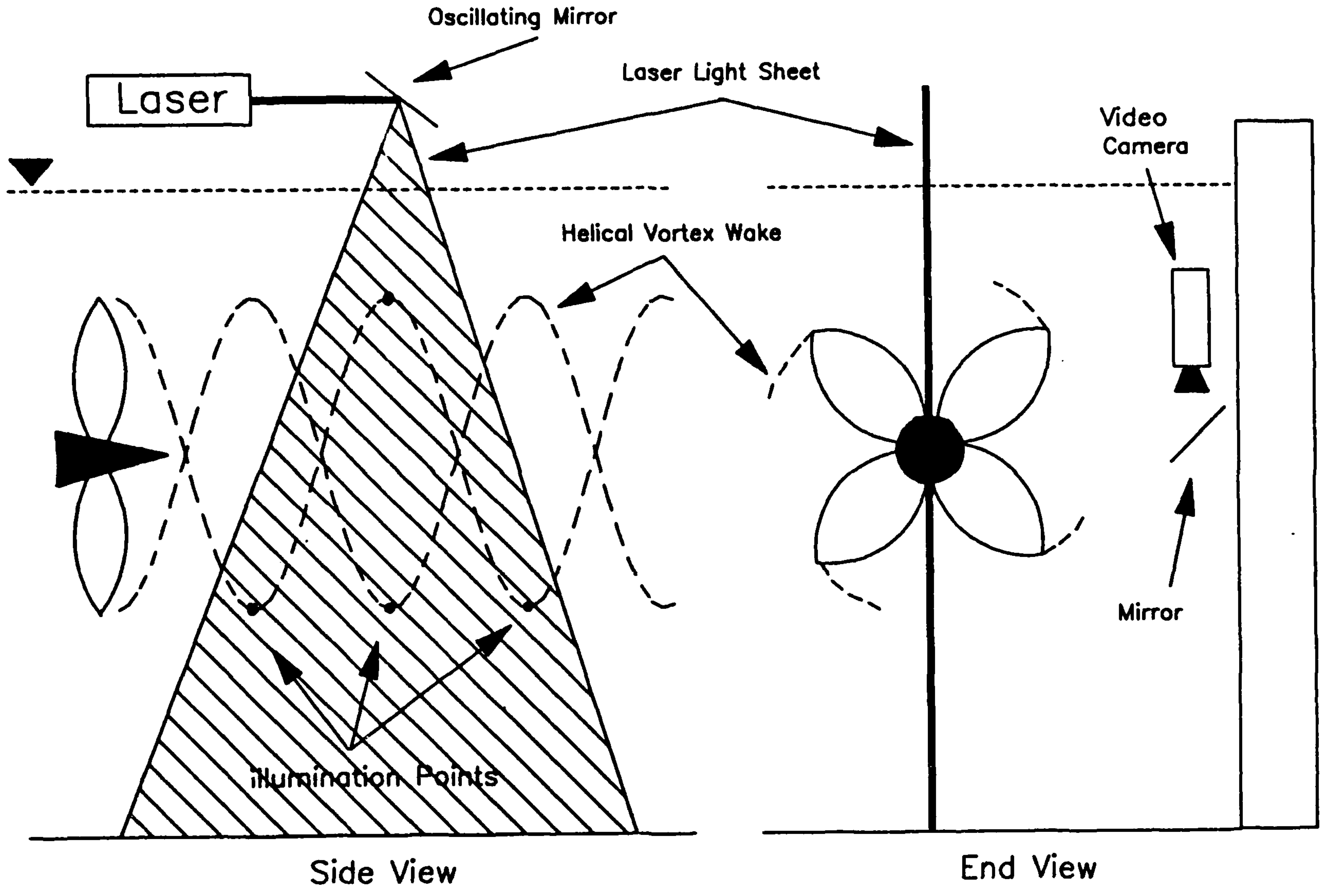
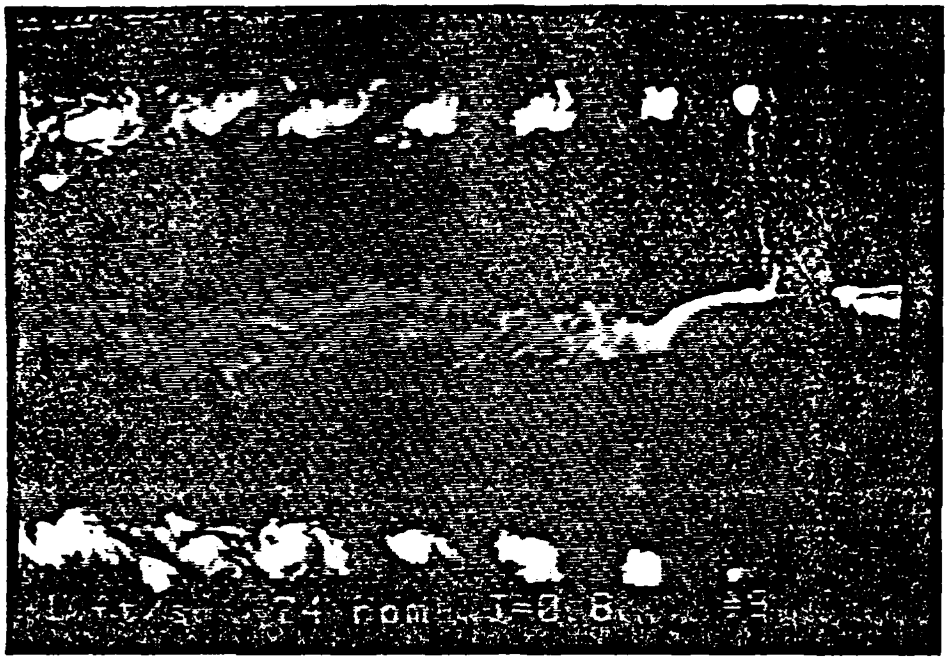


Figure 3. Laser light sheet and video camera configuration



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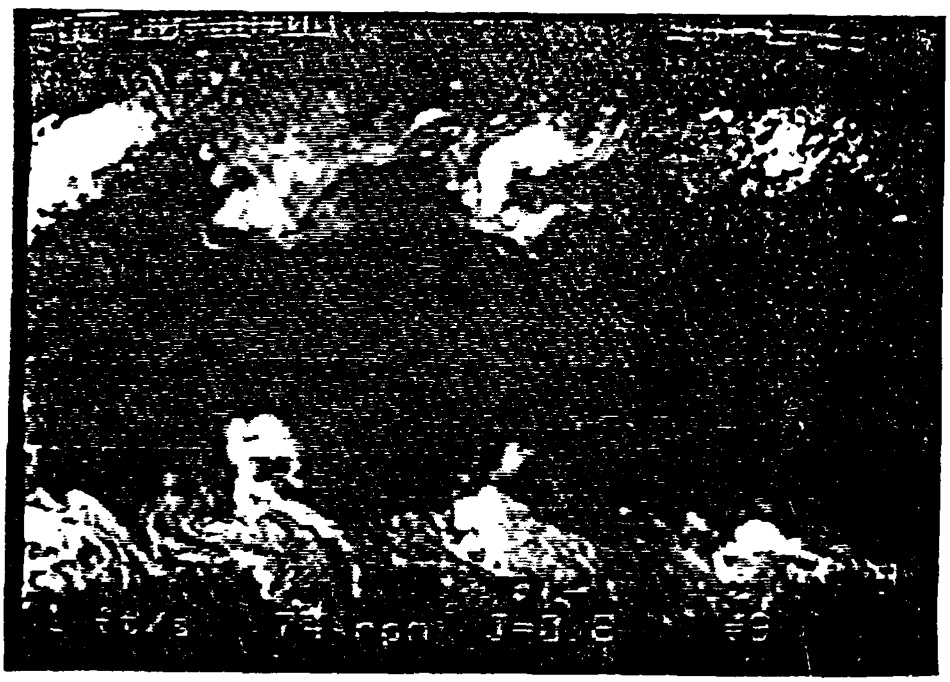

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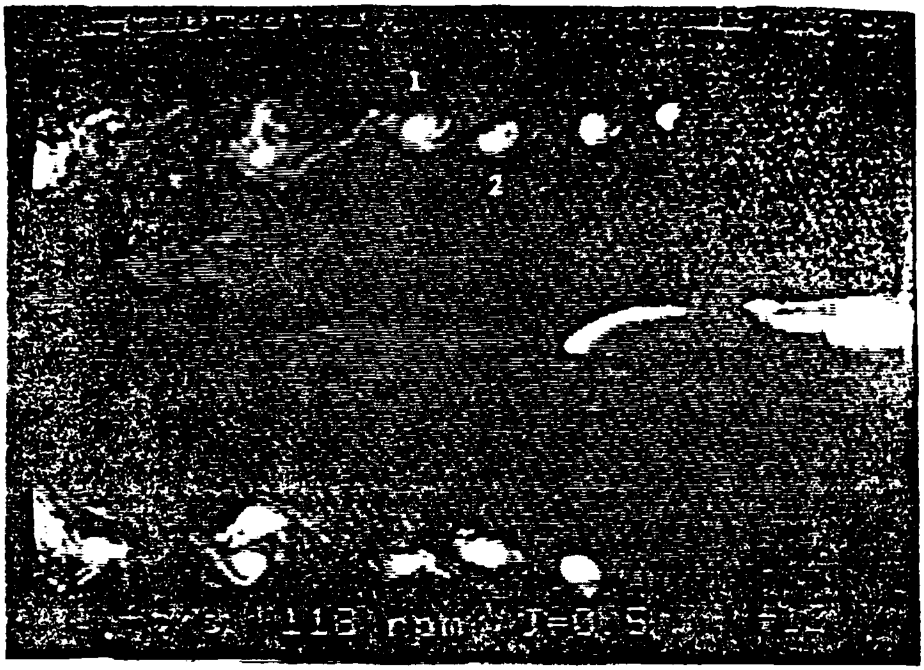
Figure 4. Video Frames: Deep Submergence, J=0.8



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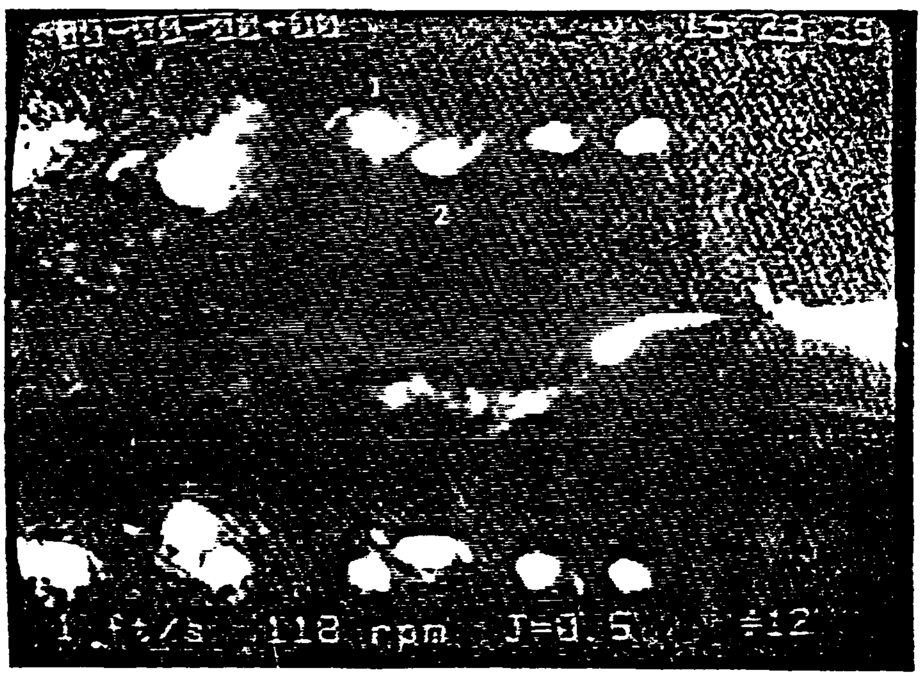

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Figure 5. Video Frames: Deep Submergence, J=0.5

(c)

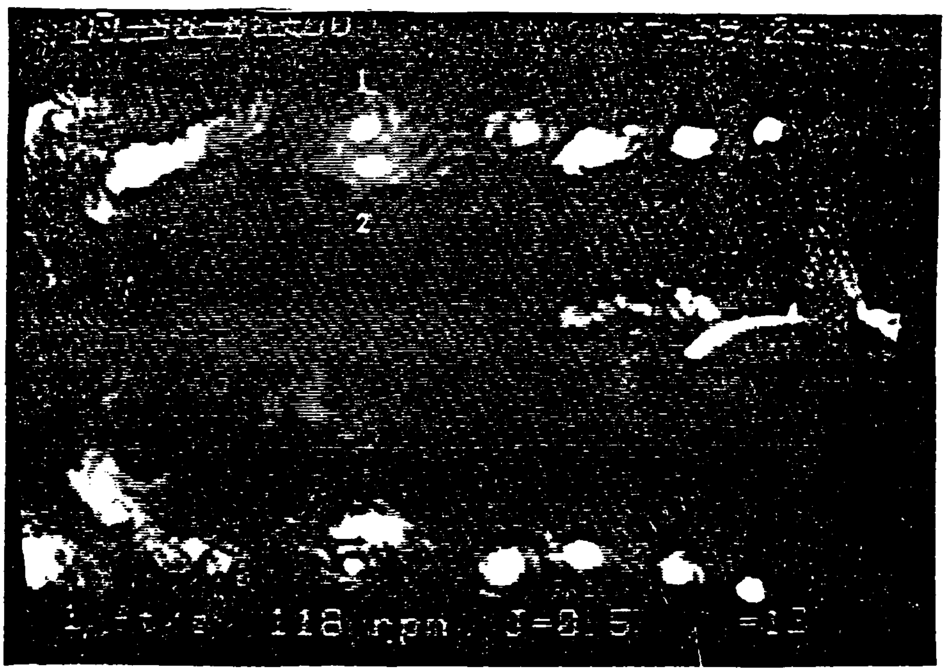

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Figure 5. Video Frames: Deep Submergence, J=0.5

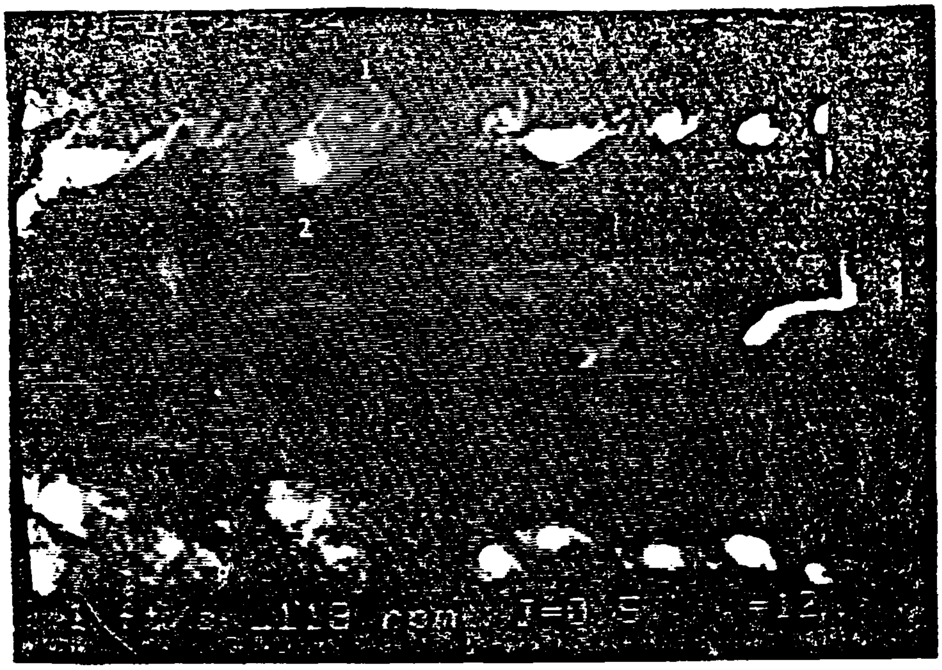

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Figure 5. Video Frames: Deep Submergence, J=0.5

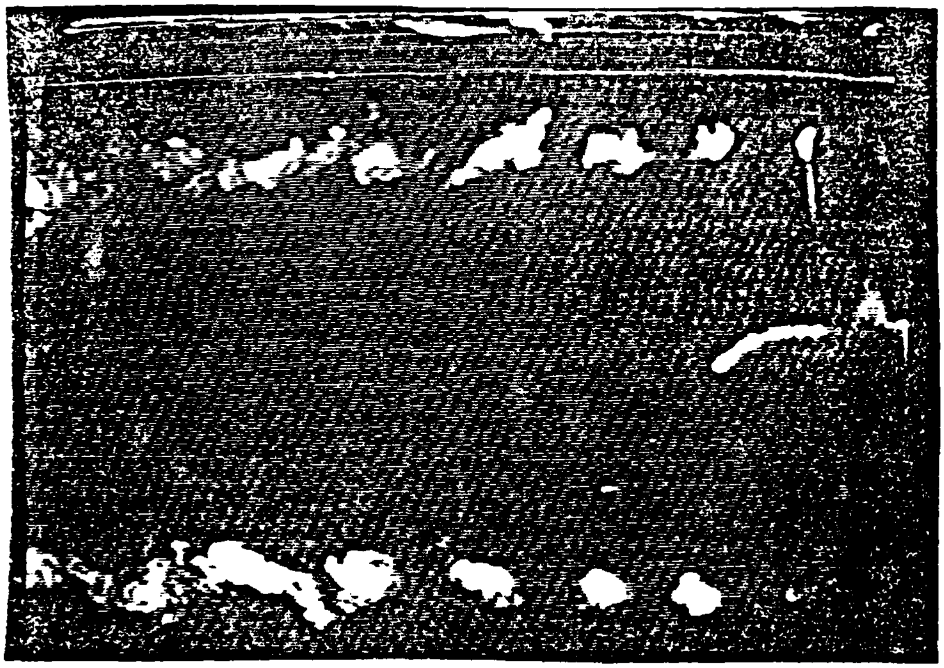
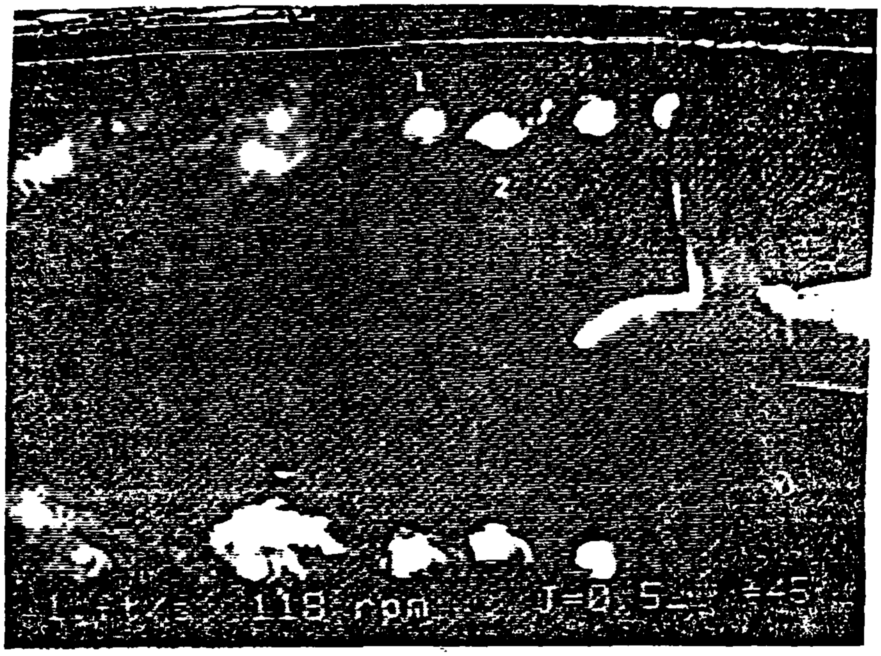


Figure 6. Video Frames: Shallow Submergence, J=0.8



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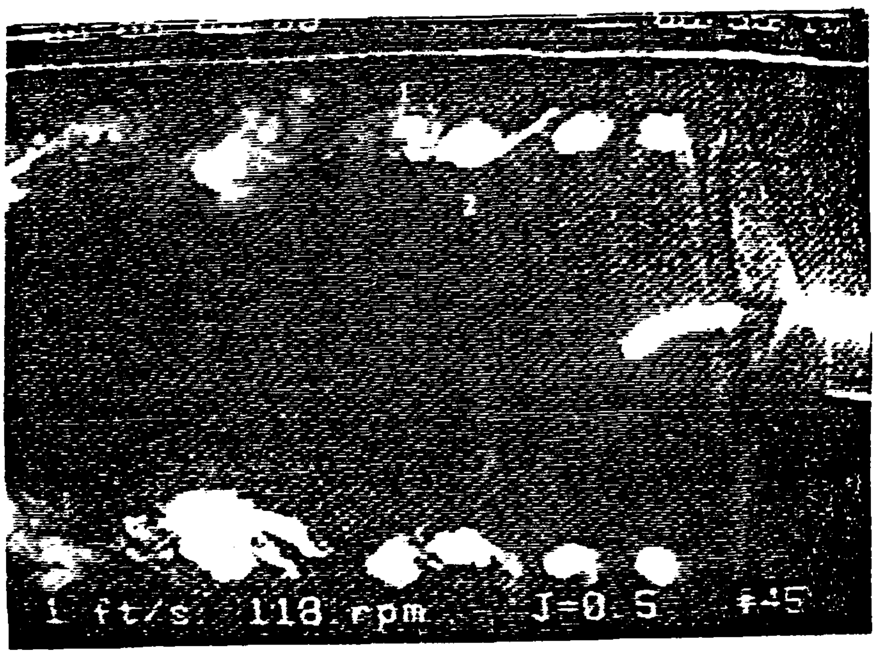

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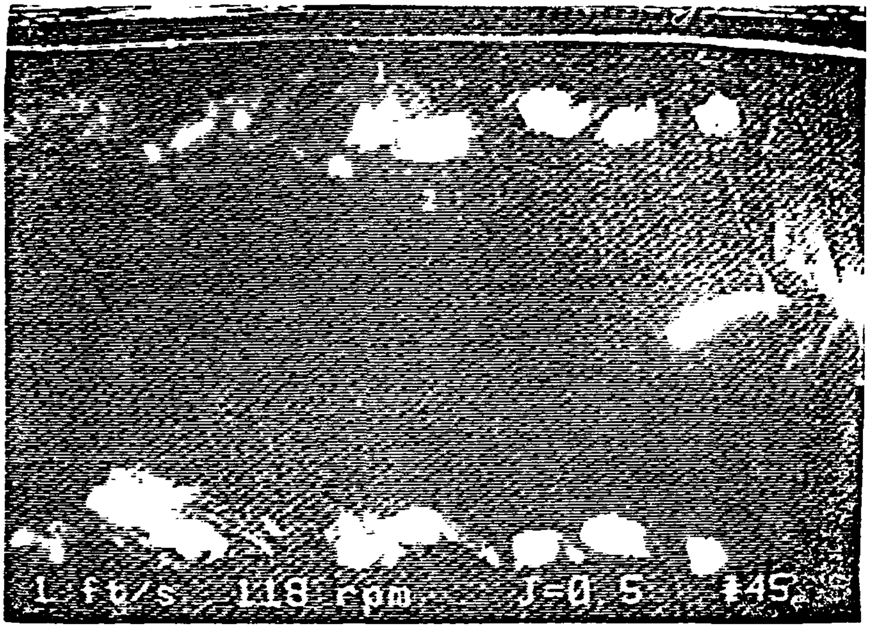
Figure 7. Video Frames: Shallow Submergence, J=0.5



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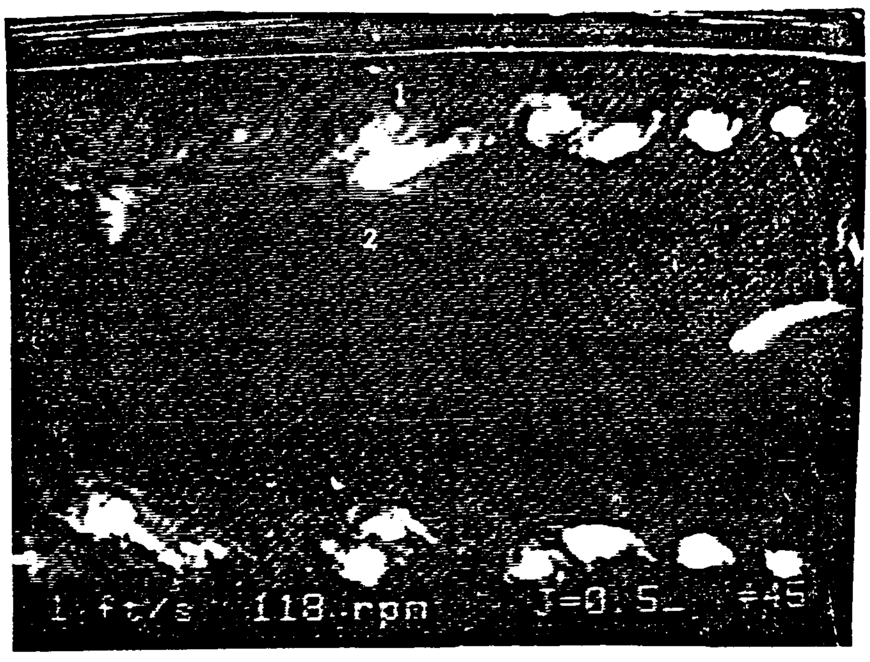

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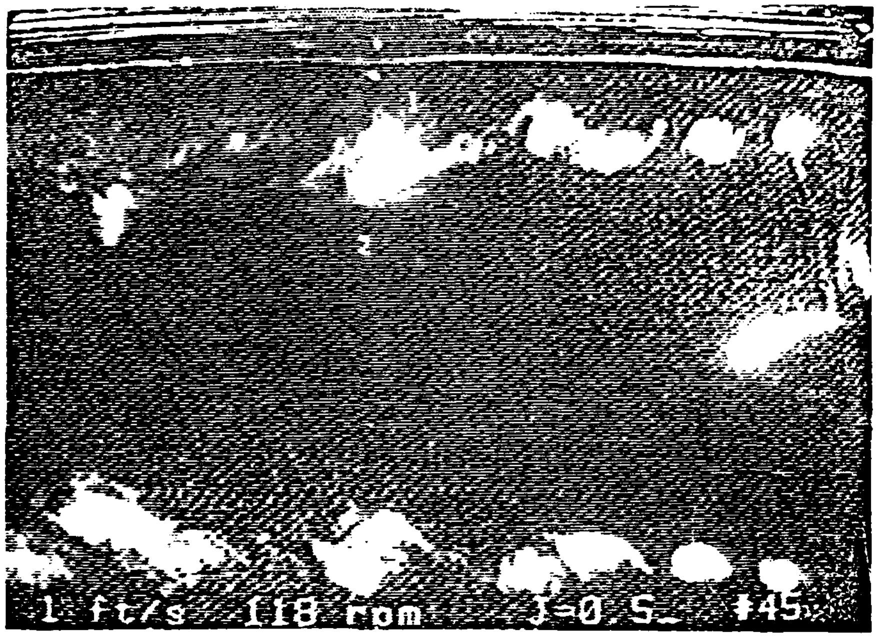
Figure 7. Video Frames: Shallow Submergence, J=0.5



(e)

Figure 7. Video Frames: Shallow Submergence, J=0.5

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