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NEAR SURFACE WAVE TURBULENCE VIA A SHADOWGRAPH TECHNIQUE

by

Ioannis K. Tsanis[1] and M.A. Donelan[2]

[1]Department of Civil Engineering
McMaster University
Hamilton, Ontario

[2]Research and Applications Branch
National Water Research Institute
Canada Centre for Inland Waters
867 Lakeshore Road, P.O. Box 5050
Burlington, Ontario, Canada L7R 4A6

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MANAGEMENT PERSPECTIVE

The transfer of toxics between air and water is controlled, to a large extent, by the turbulence on either side of the interface. In this experiment, a visual technique is used to explore the effect of the presence of waves on the turbulent intensity in the water. Initial tests indicate turbulence, and hence toxics transfer is enhanced by waves. Continuing work will address this problem quantitatively.

Dr. J. Lawrence
Director
Research and Applications Branch

PERSPECTIVE DE GESTION

Le transfert des toxiques entre l'air et l'eau est régi, dans une large mesure, par la turbulence des deux côtés de l'interface. Dans cette expérience, une technique visuelle est utilisée pour examiner l'effet des vagues sur l'intensité de la turbulence dans l'eau. Des essais initiaux révèlent que la turbulence et, par là, le transfert des toxiques, sont accrus par les vagues. Les travaux qui se poursuivent devraient aborder le problème du point de vue quantitatif.

Dr J. Lawrence
Directeur
Direction de la recherche et des applications

RÉSUMÉ

Une étude de visualisation de l'écoulement a été effectuée dans le panache d'échanges gazeux à l'Institut national de recherche sur les eaux (Centre canadien des eaux intérieures) en vue d'étudier les différents mécanismes de turbulence à proximité de la surface en présence ou en l'absence de vagues. Les expériences ont été effectuées à trois stations différentes en fonction de cinq vitesses de vent. Un projecteur de profils standard a été utilisé pour étudier le mélange de l'eau chaude et de l'eau froide sous-jacente par les courants d'impulsion et les vagues. Les profils obtenus ont été enregistrés à l'aide de photographies fixes et de caméras vidéo et analysés sur magnétoscope. Un filtrage, c'est-à-dire une amélioration de l'image et une détection des contours, a été effectué sur les profils obtenus à l'aide d'un système de traitement des images afin d'obtenir des informations détaillées sur la structure vagues-turbulence de la couche supérieure d'eau. L'épaisseur de cette couche augmente avec le temps et avec le fetch et augmente plus vite en présence de vagues. Le brassage s'étend sur toute la profondeur de l'eau à des vitesses de vent élevées et à de fortes longueurs de fetch. La formation facilement reconnaissable de nuages de bulles d'air est une autre manifestation de l'intense brassage qui a lieu dans la colonne d'eau.

Mots-clés : Projecteur de profils; traitement numérique des images; turbulence, vagues.

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I.K. TSANIS [1] - N. MERZI [2] - M.A. DONELAN [2]

[1]Department of Civil Engineering, McMaster University, Hamilton, Ontario, Canada
[2]National Water Research Institute (NWRI), CCIW, Burlington, Ontario, Canada

A standard shadowgraph system is used to study the mechanisms of near surface wave-turbulence. Warm water is mixed with the underlying cold water by drift currents and waves. The resulting shadowgraphs are recorded with photographic and video equipment. Filtering, i.e., enhancing and edge detection, is performed on the shadowgraphs via an image processing system in order to provide detailed information on the wave-turbulence structure of the aqueous upper layer.

Key Words: Shadowgraph; Digital Image Processing; Turbulence; Waves;

INTRODUCTION

Wind acting on a water body generates waves and causes a drift current. The waves release some of their energy into the turbulence when they become steep enough through breaking. The drift current is a turbulent shear flow generated by the wind stress applied at the water surface. Wave breaking plays an important role in gas transfer both for gas phase limited and water phase limited compounds; besides, dissipation of waves and generation of currents are largely influenced by breaking waves.

A flow visualization study was conducted in the Gas Transfer Flume at the National Water Research Institute (Canada Centre for Inland Waters), in order to investigate different mechanisms of near-surface turbulence in the presence or absence of waves (Merzi and Donelan, 1987). Experiments were performed at three stations and at five wind speeds. Results on the turbulence scales and thickness of the upper mixed layer as a function of both time and fetch are presented.

EXPERIMENTAL APPARATUS

The air-tight Gas Transfer flume is 31 m long, 0.75 m wide and 0.85 m high, (Fig. 1) This recirculating flume is equiped with an explosion proof motor and a fan which provides a maximum wind speed of 25 m/s; a vertical in-line water pump delivers a maximum water velocity of 0.50 m/s (Merzi, 1989).

Fig. 2 shows an overview of the experimental apparatus. Mean wind speed was measured by a Pitot Static Tube (Air-flow Development Limited, England) and a Differential Pressure Transducer (MKS Instruments Inc., U.S.A.)

The instruments used in the shadowgraph system at each fetch were a 1000 W light source, milar-type transparent paper, video camera, monitor and VCR. The light source was able to provide a parallel light beam entering the test section by using side, top and bottom plates and by placing them 5 m away, pointing at right angles to the flume, see Fig. 3. A one inch grid was printed on the transparent paper to provide a guide and comparison between experimental runs. The VCR's recorded simultaneously at the three fetches from the beginning to the end of the experimental runs. The audio signal was used for synchronization.

The video tape analysis was performed with a S-VHS AG-1830 Panasonic Industrial Video (Matsushita Ltd.) and an AGA-95 Controller that provides a clear still picture, field (1/60 sec) shift feature, slow motion and digital effects. The video and audio signals were viewed on a S-VHS Panasonic color monitor. In addition, the video signal was sent to a QuickCapture frame grabber board model DT2255-60Hz (Data Translation Inc., U.S.A.) installed into a Macintosh IIx (Apple Computer Inc.) desk top computer. Quick Capture grabs the images from the video recorder in 1/30 second (real time) and displays them on the Macintosh IIx monitor. The images can be displayed with 640 X 480 square-pixel resolution, and 256 gray levels. The images were taken from the VCR source, saved in TIFF format and printed via Image Studio (Letraset Canada Ltd.) software on a LaserWriter II (Apple Computer Inc.) laser printer. Still pictures were taken with a 35 mm single-lens reflex F3 HP Nikon camera with 50 mm Niccor lenses. Still-pictures of near-surface turbulence in the presence or absence of waves are presented in Figs. 4 and 5.

EXPERIMENTAL PROCEDURE AND RESULTS

Experiments were performed at three different fetches of 1.0, 3.95 and 11.75 m with five different wind speeds of 5, 7.5, 10, 15 and 20 m/s while the water depth was kept at 0.20 m. Warm water of 50 ^{o}C was introduced to the water surface through a diffuser system that distributes water homogeneously across the width. The water was turned off when the thermal wedge arrived at the third fetch and after a 5 min waiting period, for the turbulence induced by the diffuser to die out and the longitudinal temperature gradient to become less than 2 ^{o}C, the fan was turned on the predetermined wind speed. The wind generated a drift current and waves that caused mixing of the warm water with the underlying cold water. The consequent refractive index variations were detected using the shadowgraph technique. Three cameras, VCR's and monitors were used at the three fetches to obtain pictorial representations of the mixing phenomena.

A typical image taken from a VCR source, showing bubble penetration into upper layer following large scale wave breaking is given in Fig. 6. A number of filters can be applied to the images creating different effects. Sharpening increases the contrast of the image, edge detection enchances any black-to-white transitions within the image while histogram equalization evenly distributes the gray scale values of the pixels. Application of these filters to an image presenting the mixing of the warm to the underlying cold water at the upper layer in the presence of waves, is illustrated in Fig. 7. The interfaces (air-water and warm-cold water) and the large scale turbulence structure are clearly shown in Figs. 7(a), 7(b) abd 7(d) while the small scale structure is shown in 7(c). An enlarged portion of the shadowgraph in Fig. 7(c), revealing in more detail the turbulence structure of the mixed upper layer, is given in Fig. 8. Finally , video tape analysis reveals the time evolution of the upper layer thickness under different wind conditions for two fetches. The upper layer thickness increases with time and fetch and increases faster in the presence of waves as indicated in Fig. 9.

CONCLUSIONS

The shadowgraph technique was used for studying mechanisms of near-surface wave-turbulence. The shadowgraphs were recorded by both still photography, video cinematography and analysed with a video recorder and an image processing system. The results reveal a dependancy on mixing with the wave characteristics. In the absence of waves , the thickness of the boundary layer can be estimated via the solid wall analogy, whereas in the presence of small breaking waves, the depth of the mixed layer is of the order of one quarter wavelength. At higher wind speeds, $U > 7.5$ m/s at

long fetches, F2 and F3, the mixing extends throughout the water depth. The easily recognizable formation of air bubble clouds is another manifestation of the intense mixing in the water column.

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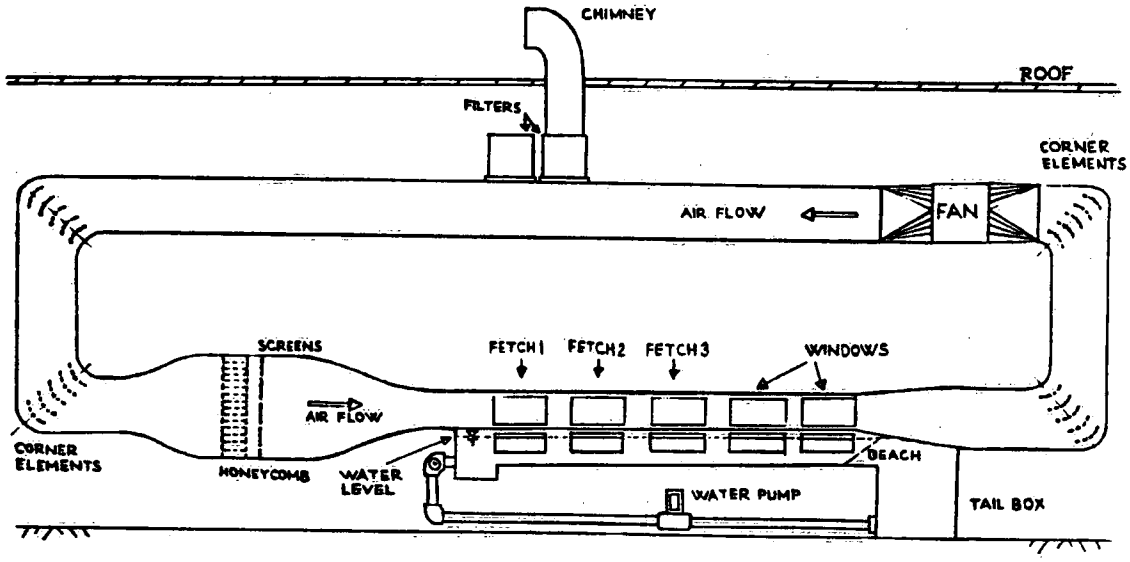

Figure 1 Diagram of the Toxic Gas Transfer Flume

Figure 2 Overview of the Experimental Apparatus

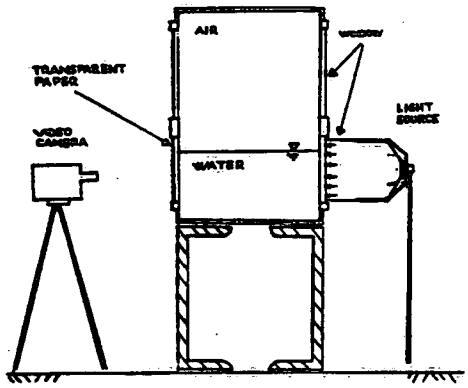

Figure 3 Shadowgraph System

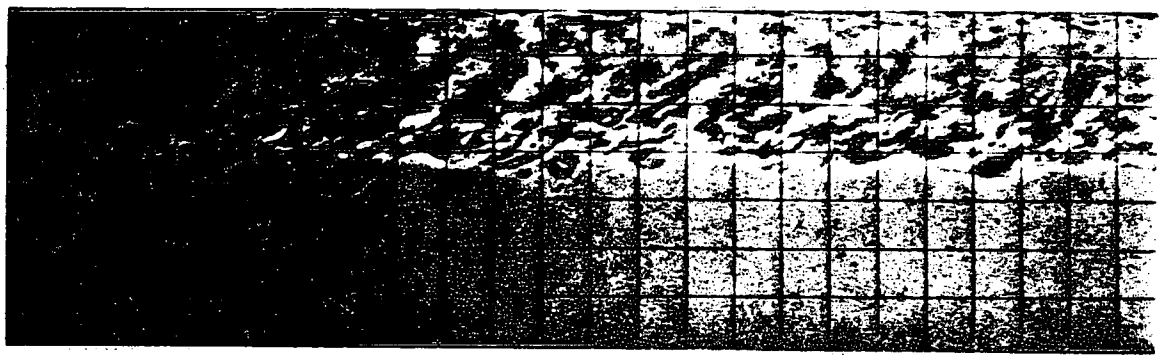

Figure 4 Still Picture of Near-Surface Turbulence in Absence of Waves (Wind duration t_S = 28 sec, Wind Speed U = 10 m/s, Fetch F = 29.5 m)

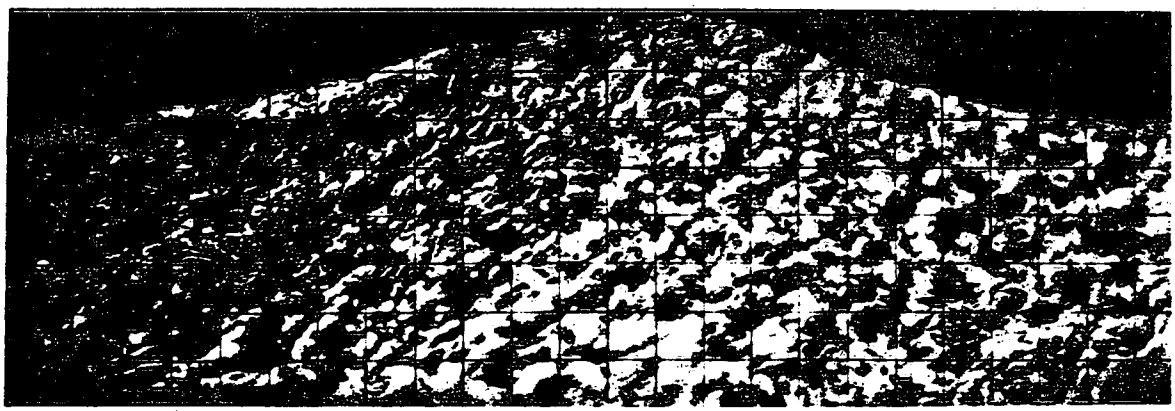

Figure 5 Still Picture of Near-Surface Turbulence in Presence of Waves (t_S = 56 sec, U = 10 m/s, F = 29.5 m)

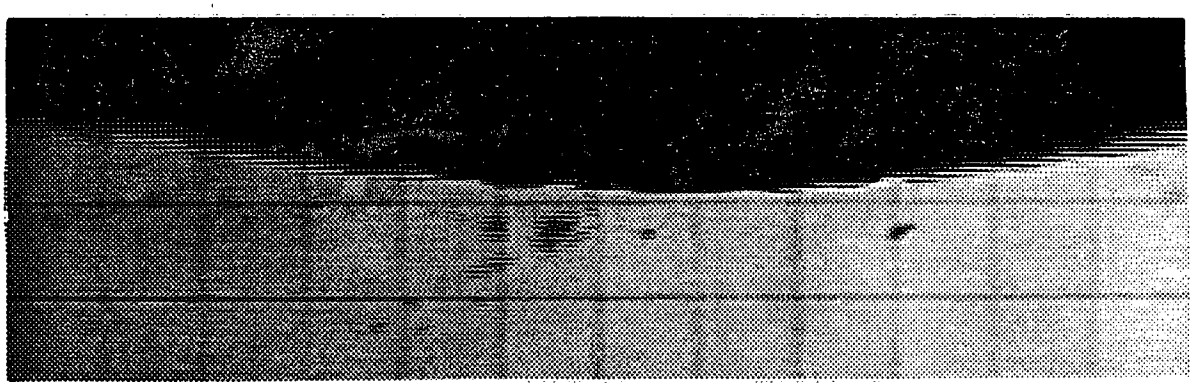

Figure 6 Bubble Penetration into Upper Layer following Large Scale Wave Breaking.

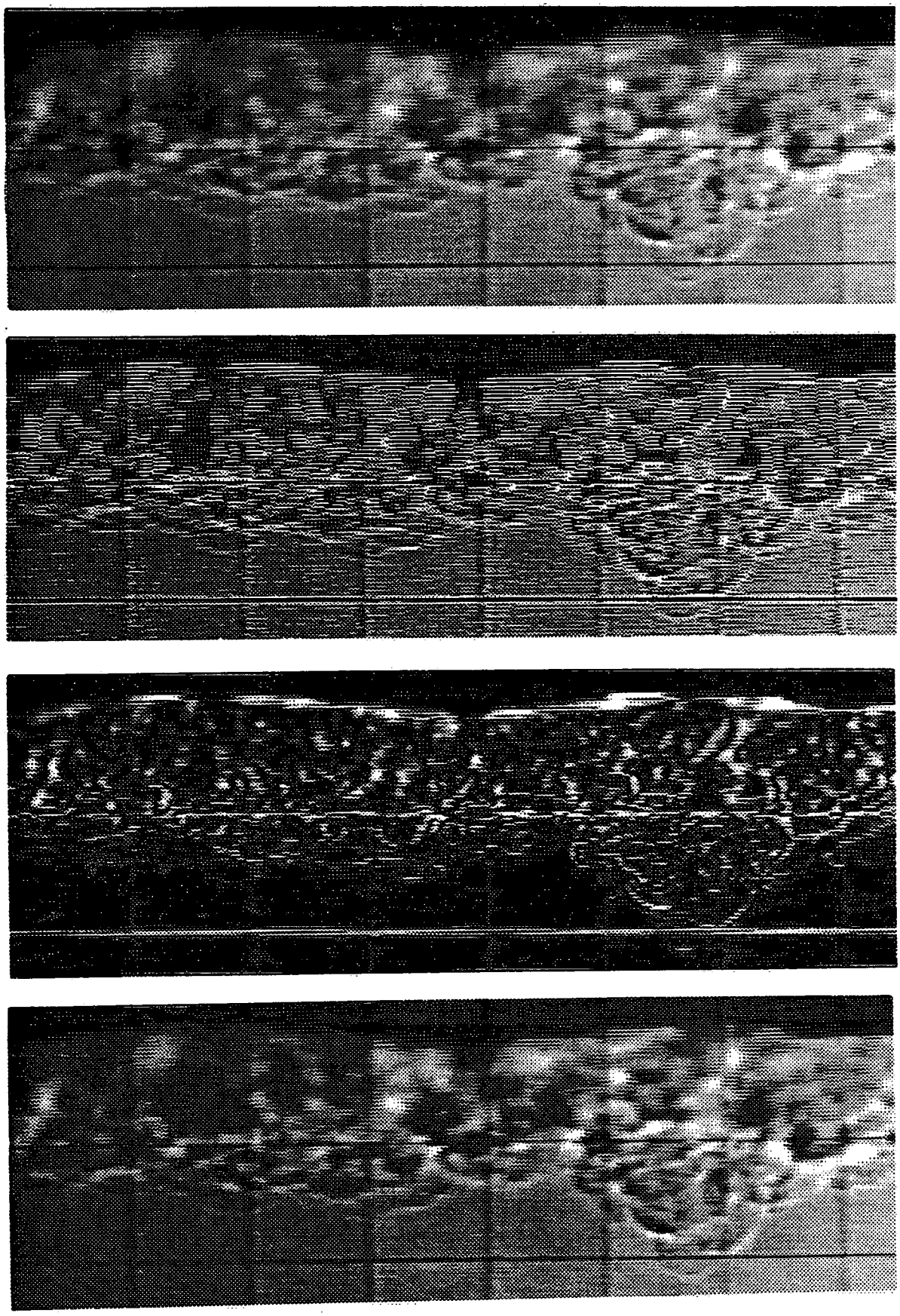

Figure 7 Filtering (a) Original Image, (b) Sharpened Image, (c) Edge Detection and (d) Histogram Equalization (t_s = 12 sec, U = 20 m/s, F = 11.75 m).

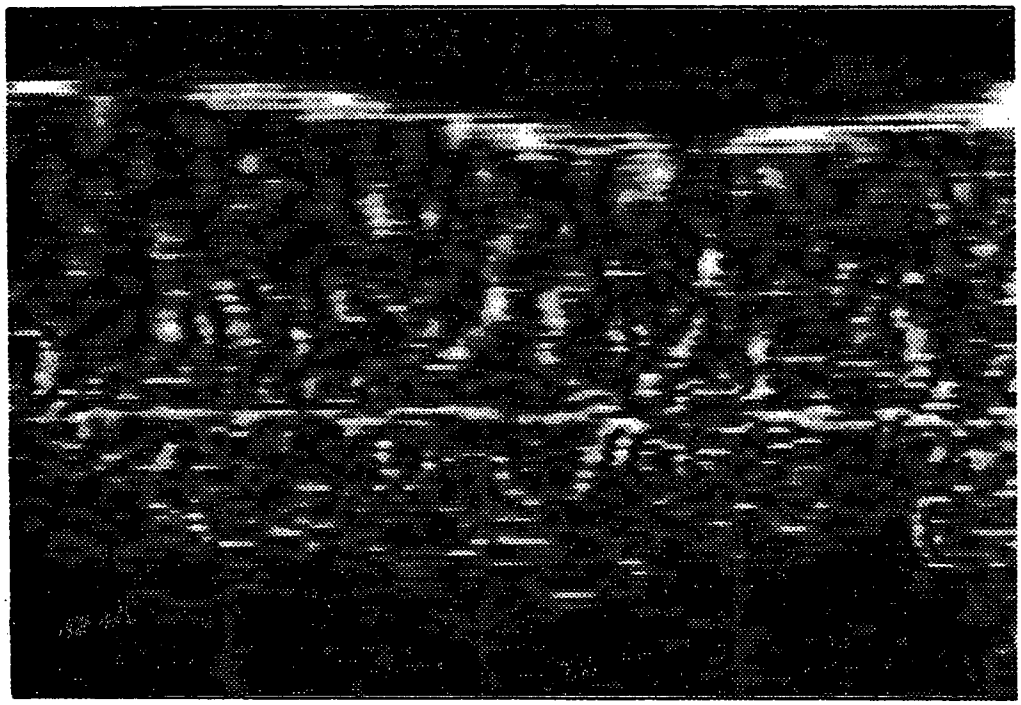

Figure 8 Blow up of a Shadowgraph of Upper Layer (t_S=12 sec, U= 20 m/s, F =11.75 m)

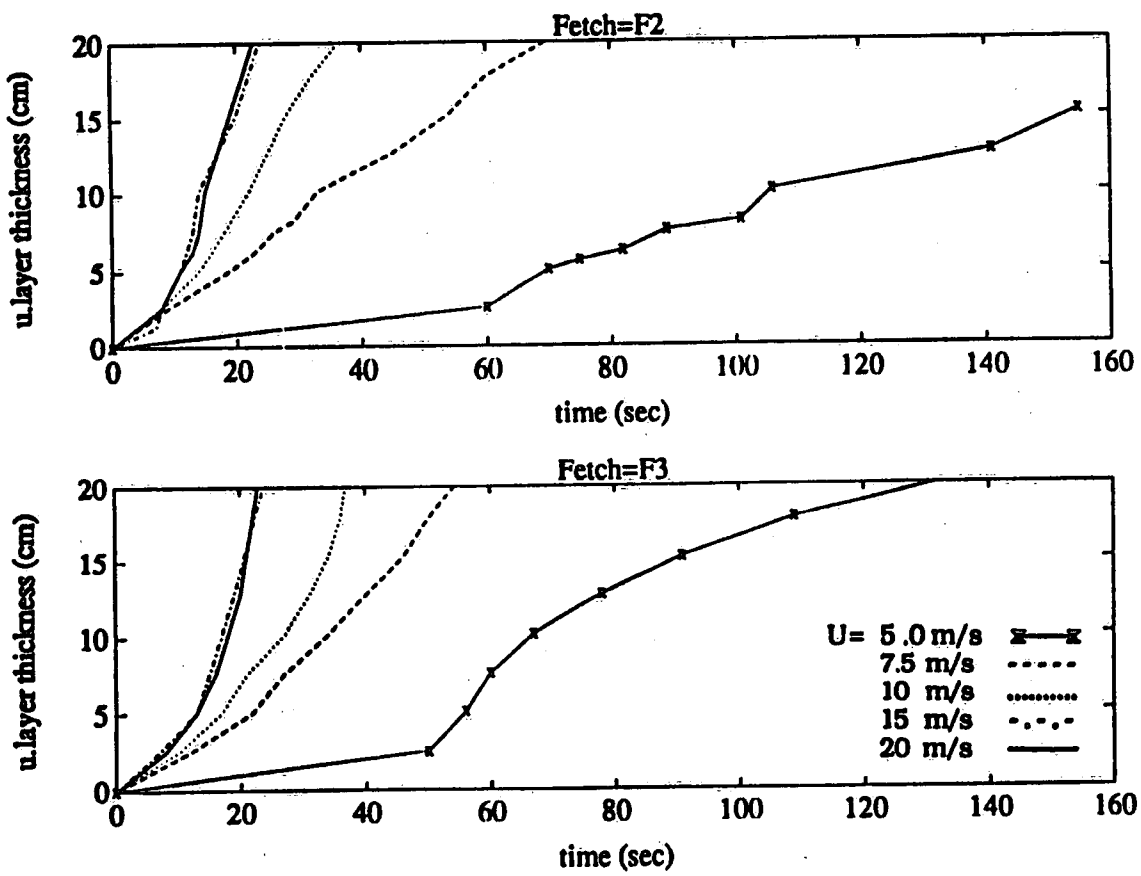

Figure 9 Time Evolution of the Upper Layer Thickness under Different Wind Conditions for two Fetches (F2 = 3.95 m, F3 = 11.75 m).