CHAPTER 6

PRESSURE DISTRIBUTION OVER A MOVING WAVY BOUNDARY

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ABSTRACT.-

Experimental data on pressure distribution over a sinusoidal wavy boundary with a fixed and a moving condition, measured in a water tunnel, are presented for a number of flow velocities. The model with the moving boundary condition is related to the situation prevailing in the steady state flow picture of a small amplitude wind-generated gravity wave in which the water flow represents the air flow in nature, while the "fixed in space" moving wavy boundary corresponds to the nearly constant water particle velocity at the surface of the wave.

The results show that the normal stress distribution over a moving boundary differs from that over a fixed one by a phase-lag with respect to the wave shape, which varies with the ratio of flow velocity to the boundary velocity (wave celerity), as predicted by the recent theories of Miles and Benjamin.

These results provide an explanation for the energy transfer from wind to wave due to normal stresses and show that those experiments performed on fixed boundary models can not be associated with the phenomena of water wave generation.

INTRODUCTION.-

Most of the experimental data available on the pressure distribution over wavy boundaries such as those of Stanton, - Marshall and Houghton (1932). Motzfeld (1937), Thijsse (1952) Bonchkovskaya (1955) and Larras and Claria (1960), were obtained from tests performed in wind tunnels or water flumes, -- using fixed boundary models built from wood or wax. (See ref. 1 or 2, for a complete experimental survey). When these pressure distributions are used to compute the energy transfer - from the wind to a gravity water wave the result is too small to explain the growth of such waves. This lack of agreement is a result of the erroneous boundary condition that prevails in the fixed boundary experiments. The flow configuration of an air flow, with velocity U blowing in the same direction of the wave train moving at a celerity c, is an unsteady one and is represented in Fig. 1. To reduce it to a steady case, a coordinate system which moves at the same speed as the wave is introduced. When viewed from the moving coordinate system the wave profile is stationary and the water flows upstream at the wave propagation velocity. The water velocity at the surface of the wave varies from a maximum at the trough to a minimum at the crest, but for small amplitudes the speed is nearly constant and equal to the same celerity c. In this steady flow picture (Fig. 2), the zero velocity point (critical level) is located at a certain height over the wave surface (critical layer), while, in a fixed boundary model this critical level is at the boundary.

Mathematical theories presented by Miles (ref. 3, 4 - and 5) and Benjamin (ref. 6) and explained from the physical point of view by Ligh thill (ref. 7), had proven that the - thickness of the critical layer plays a crucial role on the

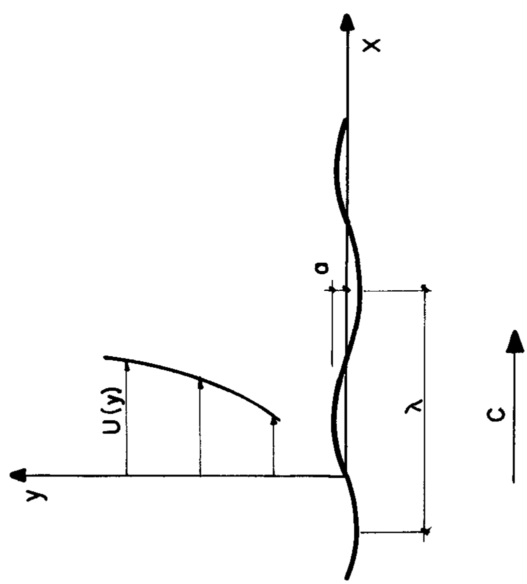


FIG 1 UNSTEADY FLOW

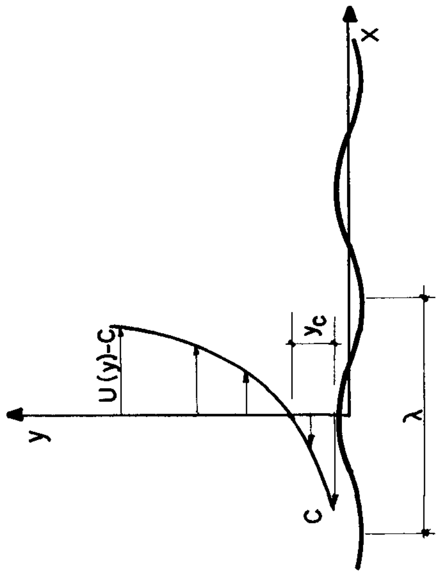
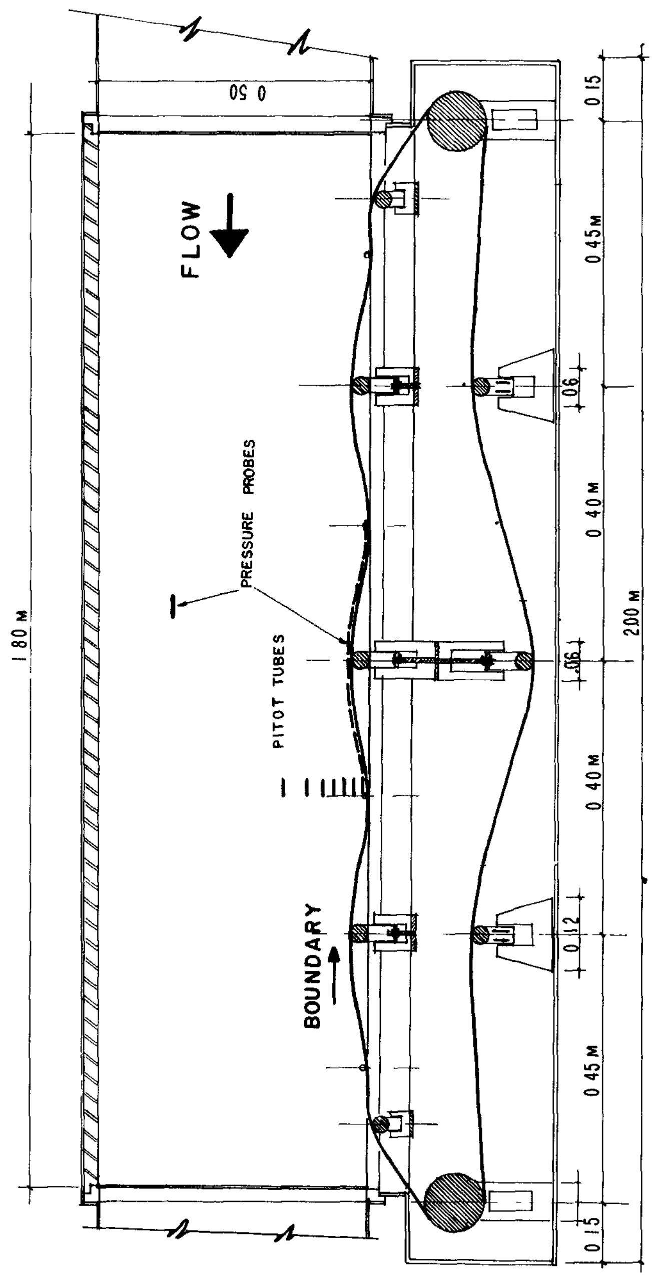


FIG. 2 STEADY FLOW

stress distribution over a wavy boundary. Previous experiments performed by the author in (ref. 1 and 2) using a model in which the moving boundary conditions were reproduced by a a belt loca ted vertically in a flume in which water was used as a working fluid, and moving at a constant speed following the shape of - the wave, have proven that the pressure distribution differs ra dically from that prevailing in a fixed boundary. While, the pressure distribution over a fixed boundary was almost in phase with the wave's shape, in the case of a moving boundary these e xists a noticable phase lag, in agreement with Miles's theoreti cal results. However, since the experimental data were obtai - ned in an open flume the range of flow velocities was very small due to the appearance of surface disturbances which affected the already small magnitudes of the pressure (the boundary has moved at a fixed speed, which corresponds to the celerity of a gravity wave with the same wave length). In order to increase the range of flow velocities and improve the precision of the measurements, a different experimental set-up had been designed.

EXPERIMENTAL SET-UP.-

The moving boundary conditions were reproduced by a cold rolled stainless steel band 10 cm. wide and 3 mt. long located in a water tunnel with a test section 2 mt. long and 10 cm. x - 50 cm. cross section. The wavy boundary was formed by 3 waves with 40 cm. wave length, and the mechanism was such that the amplitude could be changed easily, starting from a flat surface and increasing to a large ratio of amplitude to wavelength. To produce the wavy form the stainless steel band had a fixed su - pport at the trough and a movable support at the crest. The thickness of the band and the diameter of the supports was se - lected in such a way that the wave's shape approximates a sinu-soidal one. The speed of the moving boundary was set to be e - qual to a celerity of a gravity wave with 40 cm. wavelength -



TEST SECTION

FIG. 3

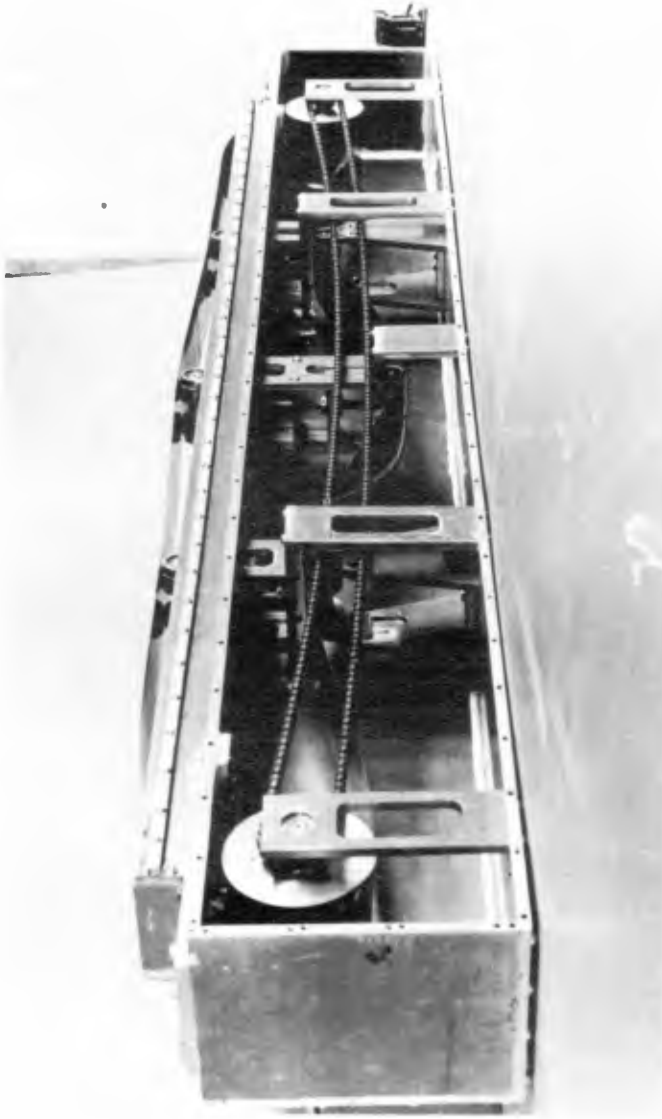


Fig. 4 View of the moving boundary mechanism.

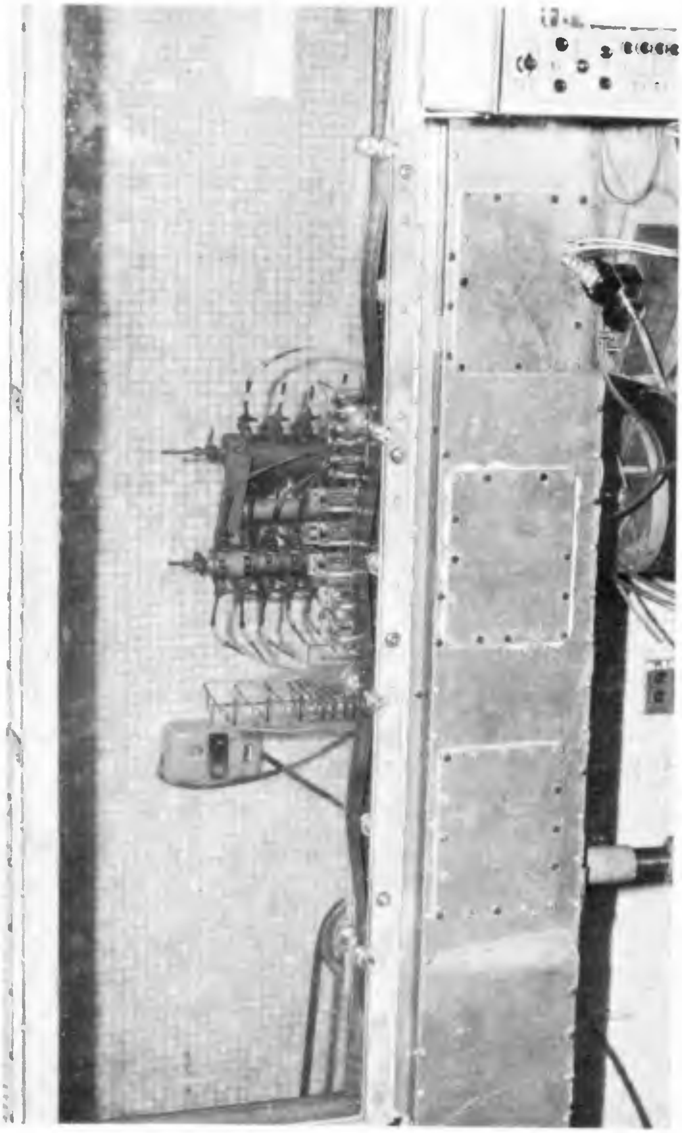


Fig. 5 General view of the test section.

(0,79 m/seg), althoagh it could be changed to any other value through a system of pulleys connected to an electric motor with a speed reductor. Water could flow at a maximum speed of 3 mt/sec. and the velocity could be controled by a valve loca - ted downstream of the test section. Care was taken to obtain a well developed turbulent flow at the upsteam part of the test section, and for that reason a series of honey combs were pla - ced in several sections of the apparatus. The sketch of the test section is shown in Fig. 3, and the photographs of Fig. 4 and 5 shows the detail of the moving boundary mechanism and the general view of the aparatus.

Velocity measurements were made at the trough of the cen tral wave using a number of small pitot tubes (1/8" O. D.) pla - ced in the back side of the test section. In the inmediate vici nity of the boundary some of the pitot tubes were placed in the opposite direction so as to measure velocities in the critical layer. Pressure distribution was obtained with static pressure probes (1/8" O.D.) located parallel to the moving boundary at a 1/4" from it. These probes were placed every 1/8 of the wave length and were mounted at the back side of the test section in such a way that it was possible to adjust the height, the depth, and the inclination of the probe. Preliminary experiments showed that the pressure variation accross the test section was very small at the central part, and that the selected hieght of the probe was the most adequate one.

All the measurements were performed at the mid section of the central wave, using differential pressure transducers model PACE P90 (range ± 1 in of water) with a Sanborn two cha - nnel thermal recorder model 320.

EXPERIMENTAL RESULTS.-

Pressure and velocity distribution measurements were performed for stationary and moving boundaries with three di - fferent wave amplitudes and several flow velocities. The wave

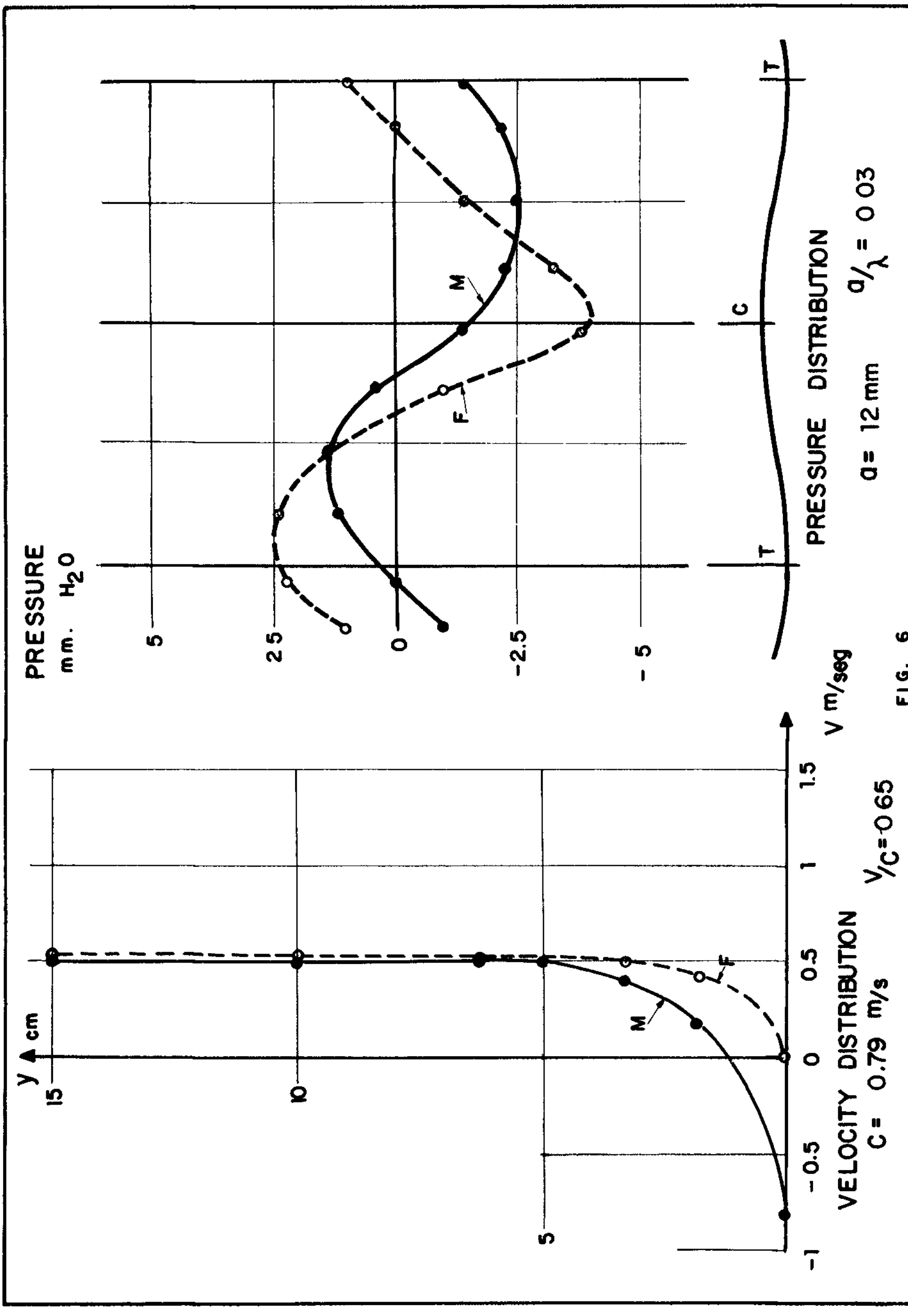

PRESSURE
mm. H_2O
5
2.5
0
-2.5
- 5
T
C
T
M
F
PRESSURE DISTRIBUTION
a = 12 mm
a/λ = 0.03
y cm
15
10
5
-1
-0.5
0
0.5
1
1.5
V m/seg
M
F
VELOCITY DISTRIBUTION
C = 0.79 m/s
V/C = 0.65

FIG. 6

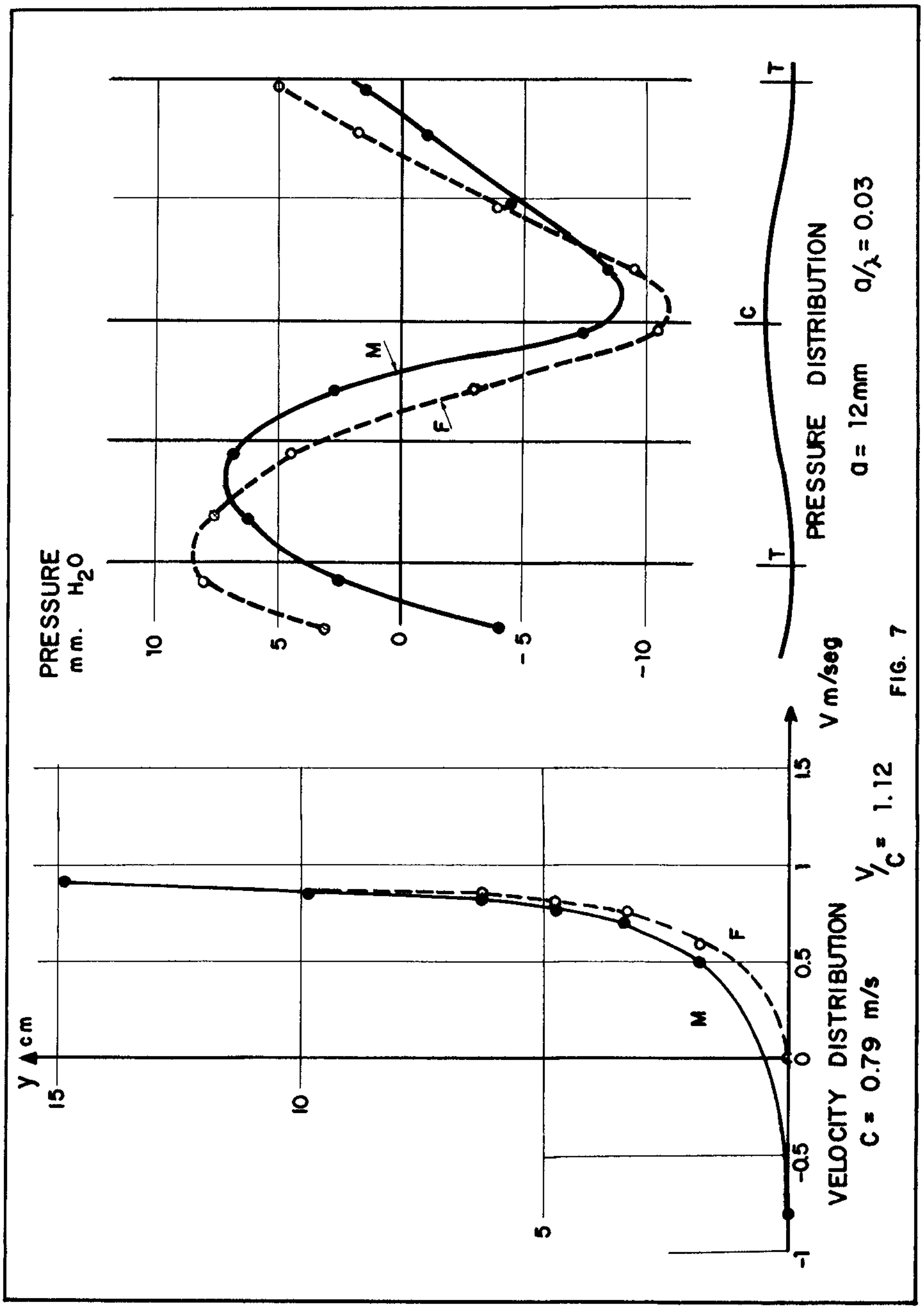

PRESSURE
mm. H_2O
10
5
0
-5
-10
M
F
T
C
T
PRESSURE DISTRIBUTION
a = 12mm
$a/\lambda = 0.03$
y cm
15
10
5
M
F
-1
-0.5
0
0.5
1
1.5
V m/seg
VELOCITY DISTRIBUTION
C = 0.79 m/s
$V/C = 1.12$

FIG. 7

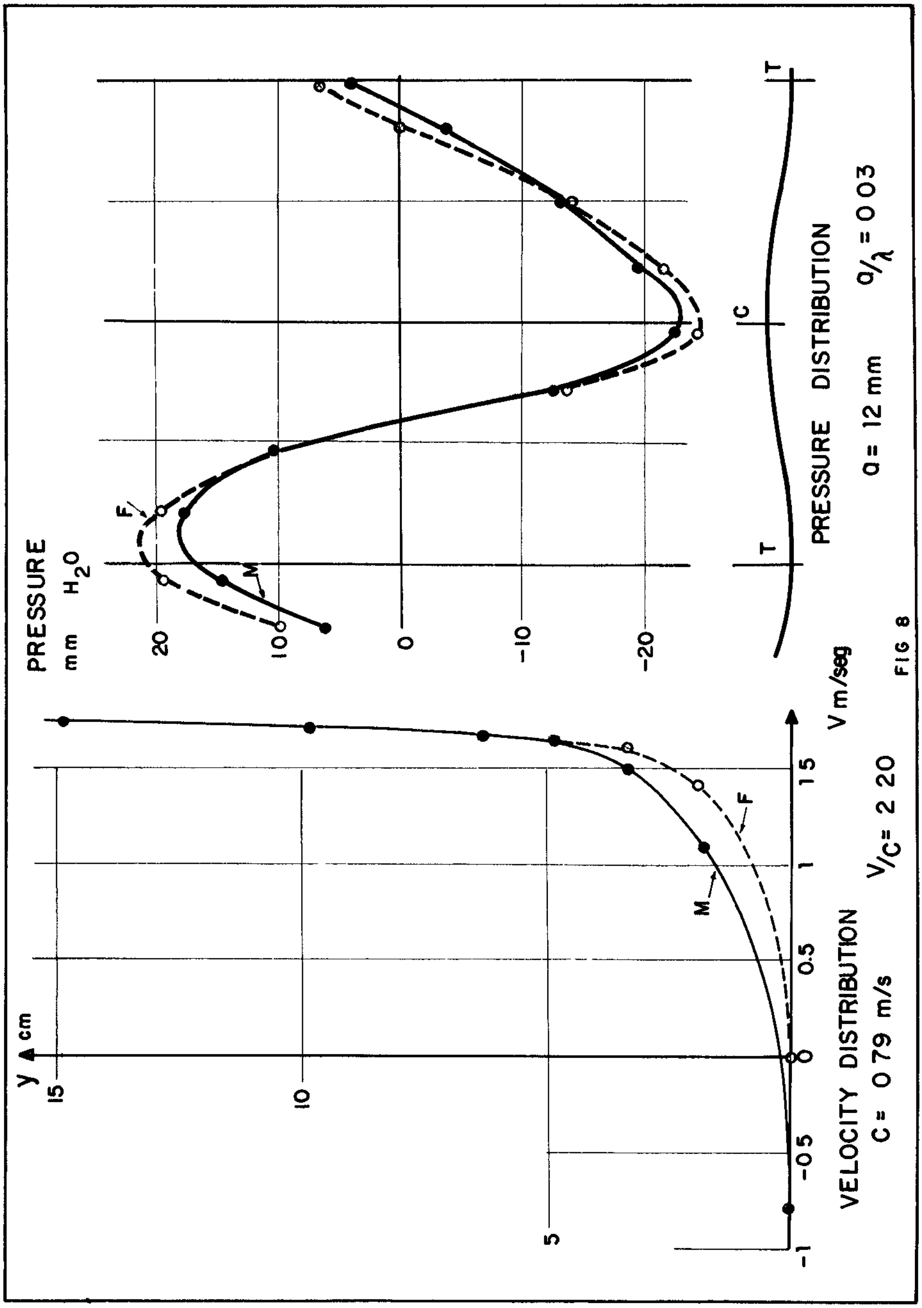

PRESSURE
mm H2O
20
10
0
-10
-20
F
M
T
C
T
PRESSURE DISTRIBUTION
a= 12 mm
a/λ = 0 03
y cm
15
10
5
-1
-0 5
0
0.5
1
1 5
V m/seg
M
F
VELOCITY DISTRIBUTION
C= 0 79 m/s
V/C= 2 20

FIG 8

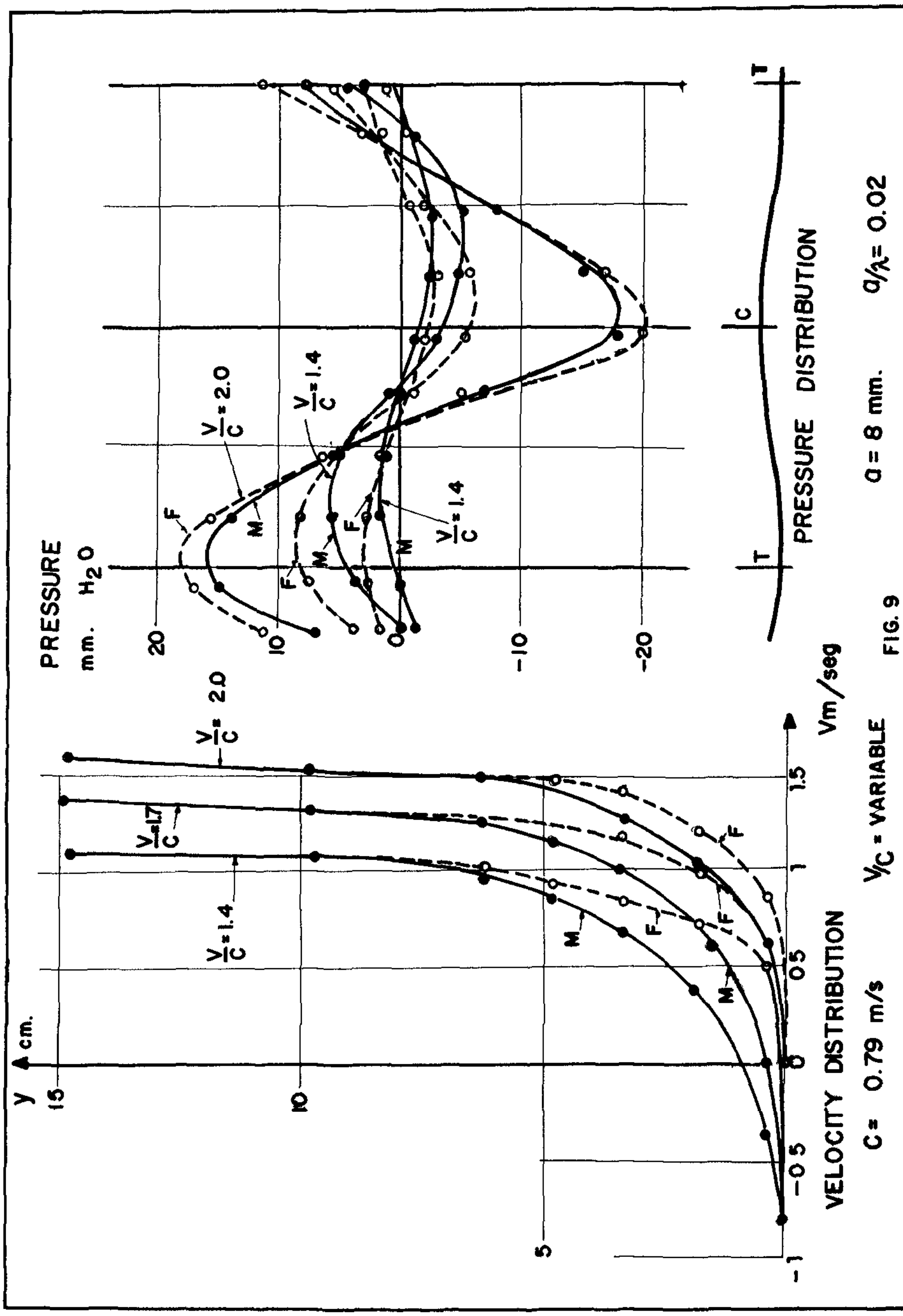

PRESSURE
mm. H_2O
PRESSURE DISTRIBUTION
a = 8 mm.
a/λ = 0.02
VELOCITY DISTRIBUTION
C = 0.79 m/s
V/C = VARIABLE
Vm/seg
y cm.

FIG. 9

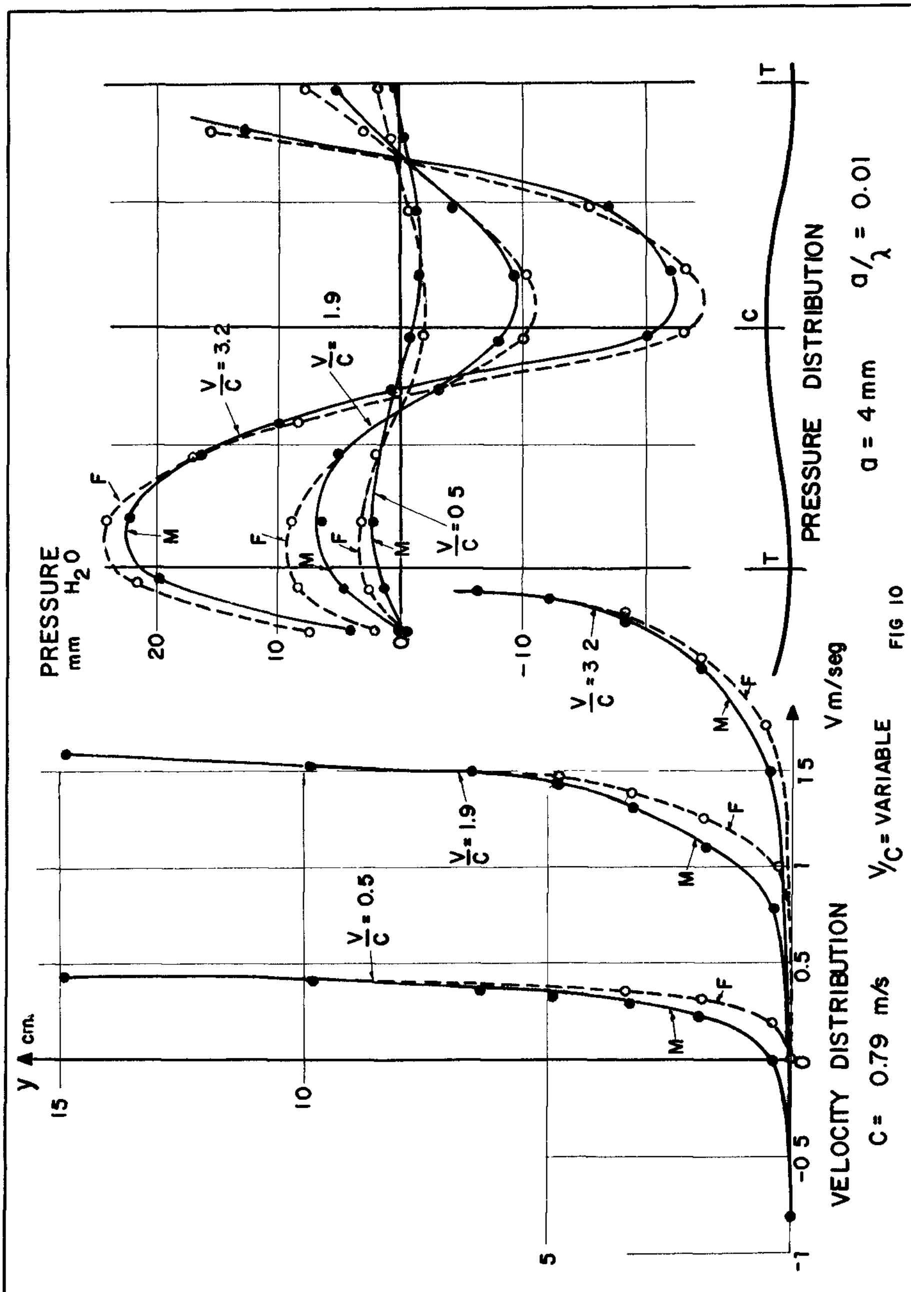

PRESSURE mm H_2O
20
10
0
−10
V/C = 3.2
V/C = 1.9
V/C = 0.5
V/C = 3 2
F
M
T
C
T
PRESSURE DISTRIBUTION
a = 4 mm
a/λ = 0.01
y cm.
15
10
5
V m/seg
−1
−0 5
0
0.5
1
1.5
VELOCITY DISTRIBUTION
C = 0.79 m/s
V/C = VARIABLE

FIG 10

amplitude varied from 4 mm. (a/ = 0.01) up to 12 mm. (a/ = 0.03) and the flow velocities changed from aproximately 0,5 m/seg. up to 3 m/sec. No higher wave amplitude were tested because the boundary conditions at the wave surface would differ considerable from the constant velocity prevailing in the model. The series of graphs given in Fig. 6, 7 and 8 show the corresponding velocity and pressure distribution curves for both boundary conditions when the wave amplitude is 12 mm. and the ratio of maximum flow velocity to wave celerety is 0,65, 1,12 and 2,20 respectively. From this figures it is possible to observe the phase-lag existing in the moving boundary as compared with the fixed boundary condition. This difference is largest when the ratio of flow and boundary velocities is small, and diminishes when the flow velocity increases, as it is expected from the theory.

In Fig. 9 and Fig. 10 the results for several ratio of flow and boundary velocities are presented, for wave amplitudes of 8 and 4 mm. respectively. In these graphs the same trend can be observed for the pressure distribution curves with the moving boundary condition.

CONCLUSIONS.-

The experimental pressure distribution curves obtained for the moving boundary conditions confirm the theoretical prediction of the phase-lag existing in the pressure curve, and explain the phenomena of energy transfer from wind to a water wave due to the normal stresses. This phase-lag become smaller as the flow velocity increases and at very high flow speeds the fixed and moving boundary pressure distribution become almost identical.

This results prove the importance of representing the right boundary conditions when dealing with a model of wind generated waves and show that the previos experiment performen in wind tunnel or water flumes using a fixed wavy boundary can not be directly related to wind generated water waves.

ACKNOWLEDMENTS.-

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