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By

W.E. Gray, D.F.C.

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MEASUREMENTS OF "AQUAPLANING HEIGHT" ON A METEOR AIRCRAFT, AND PHOTOS OF FLOW PATTERN UNDER A MODEL TYRE

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SUMMARY

Experiments with a "Meteor" aircraft to measure the gap between tyre and runway under high speed and flooded conditions are described. Water depths were varied from $\frac{1}{8}$ in. to 1.0 in., and most of the tests were at 90 knots, at which speed the tyre was well off the ground in $\frac{1}{4}$ in. of water. Clearances were measured by small ridges of plasticine, and some evidence was obtained of tyre distortions and of water velocity under the tyre.

Qualitative studies of the liquid thickness in the footprint area of a small model tyre were made and photographs taken showing the flow directions and velocities under the tyre. To do this the model tyre was run in contact with the inner wall of a transparent drum. A selection of photographs is given.

Replaces R.A.E. Tech. Note No. Aero. 2855 - A.R.C. 24669.

LIST OF CONTENTS

LIST OF ILLUSTRATIONS

1 INTRODUCTION

This Note presents a summary of the results of full-scale tests with a Meteor last January, and the salient points from a fairly thorough series of aquaplaning tests on a small model pneumatic tyre running in a perspex drum; these have been done since, as a qualitative study and an aid to interpretation of the Meteor results.

The aim of the Meteor experiment was to establish the water layer thickness involved in aquaplaning, so as to be able to get to grips with the problem. The NASA have discussed the phenomenon in general terms for several years, but do not seem to have attempted any direct measurements of thickness.

The model tests show that the kind of tyre/water behaviour found on the Meteor applies to a wide range of variable conditions on the model.

It is thought by the author that a sufficient general picture of the phenomenon is now presented to justify turning serious attention to looking for remedies for aquaplaning. The fuller study of the behaviour with bigger models, and the mathematical study of the problem can be going on meantime.

2 ESTIMATION OF AQUAPLANING SPEED

The only theoretical comment that will be made here concerns the current NASA formula[1] for estimating this speed, in that it contains an empirical factor of 0.7 which does not seem to be explained or understood. It is assumed that the "footprint" area remains unchanged when aquaplaning; it seems also to be taken for granted that when the hydrodynamic stagnation pressure corresponding to the aircraft speed is equal to the tyre internal pressure the water <u>ought</u> to penetrate the footprint (i.e. not be squeezed out), ought to retain this pressure uniformly, and therefore, support the aircraft on water only. Experimentally it was known that the speed had to be raised nearly 20% before aquaplaning was considered to begin, so the lifting power (C_L) of the water was written down to 0.7 in consequence.

It would seem that the effect of the mass of the tread rubber continuously impinging on the runway at the front of the footprint and having its vertical velocity abruptly arrested has not been taken into account as such at all/: this effect must greatly increase the contact pressure locally, and so prevent penetration by the water until a higher forward speed is reached.

A tentative calculation shows this effect to be of the right order to account for the empirical factor of 0.7 on a full size aeroplane, and the same applies to the model experiments described here, which show a similar "factor".

3 METEOR TESTS

A Meteor aircraft was run through a large pool of water on the main grooved Farnborough runway, about 150 ft long in the deepest tests. Depth was varied from $\frac{1}{8}$ in. to 1 in., and the gap between tyre and runway was recorded by the simple method of running over ridges of plasticine; these were laid on or fixed to the runway under the water, and by choosing a size to suit each test so as not to involve excessive flattening, false answers were avoided. The actual sizes of plasticine ridge used are shown in Fig.1,

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/The stiffness of the tyre presumably also has some influence.

the triangular sections being attached to the runway and the $\frac{1}{4}$ in. round section being unattached. The nose wheel was kept just clear of the water, and the load on a main wheel was determined from photos of the oleo deflection; each main wheel carried about 2 tons, the aerodynamic lift being small (incidence = 2°).

The results are shown in Fig.1 where the curve is for tests at 90 knots, with a single test point at 60 knots. The main curve is for the lowest point of the tyre, but a peculiar effect was found in very shallow water (0.125 in. to 0.21 in.) when the centre of the tread was not the lowest point. Readings 20 feet after entering the pool corresponded with readings 100 feet later just before exit, and readings with plasticine fixed to the runway were consistent with tests where the plasticine was free and was pushed forward by the water before and after being run over.

There is clear evidence that in the deeper water (0.8 in.) the plasticine was gripped near the edges of the "footprint" while the water pushed the middle part forward before it was finally pinned down by the rubber (see Fig.2). This is consistent with the model tests, which show the water under the centre to be carried along at roughly one third of the aircraft speed.

In water approximately $\frac{1}{8}$ in. deep the edges of the footprint were about $\frac{1}{2}$ millimetre off the runway while the centre of the tread was more than 1/10 in. off, the precise amount being unknown (See Fig. 2).

The Meteor tyres were grooved tread 32 in. × 10 in. at about 63 lb/sq in. and the load on each was about 2 tons. There were eight circumferential grooves 0.2 in. × 0.2 in.

When the plasticine was fixed to the runway the passage of the tyre "scuffed" it forwards where it touched it, showing that the wheel r.p.m. had dropped on entering the water. NASA tests[1] published in February gave measurements of wheel "spin-down" in slush, amounting to some 50% in 2 seconds. A check on the Meteor showed a 10% drop in 0.17 seconds and 20% drop in 0.45 seconds, on the limited pool; these values are comparable with the U.S. tests.

4 MODEL TEST CONDITIONS

Tests were done with a 4.5 in. × 1.5 in. model aeroplane pneumatic tyre with no canvas in it; the tread was ground off to give a smooth tyre of about 1/16 in. rubber thickness, and the inflation pressure was about 6 lb/sq in.

The model wheel was run in the inside of a perspex drum of 8 in. diameter so that the flow could be studied. At 50 ft/sec peripheral speed the "g" on the water layer was about 250, but the resulting pressures are still small in relation to the tyre and hydrodynamic pressures; the contact area of the footprint is of course elongated by the curvature; these departures from real life are minor ones in a qualitative test.

Experiments were done with water, in depths up to $\frac{1}{4}$ in., but to get photographs of polythene particles the density had to be changed by adding acetone to give a 50/50 mixture, whereas to get photographs of the liquid thickness 10% condensed milk was added to water. While these changes reduced the rubber/perspex wet friction they hardly changed the aquaplaning flow characteristics.

To show the flow velocities as well as directions a finite exposure of 1/4000 second was used, with an effective exposure for a moving particle of only 1/100,000 second; continuous lighting and 250 frames/second recorded transient conditions. Negative prints have been obtained as they are thought to be clearer. The blurred start and finish of each streak is due to the cine camera shutter having to cut the light beam where it is relatively wide.

5 MODEL TEST RESULTS

Penetration of the liquid under the centre of the tyre started at about 35 ft/sec in 1/32 in. of liquid and at about 40 ft/sec in $\frac{1}{8}$ in. depth. Without going so far as to define this as the onset of aquaplaning it is obviously a very significant feature; it is easy to see, and thus is a good yard-stick. The resulting characteristic U-shaped pattern dominated most of the tests, although it was less marked and smaller as the liquid depth increased; it became more marked with increase of speed, but was little affected by change of slip ratio from 0% to 100%. On "touch-down" in the drum the U was established within 1 ft of travel, and the photos in Figs.6-9 were taken during the first revolution of the drum after the tyre made contact in the water.

The bottom of the U is near the rear of the nominal (static) footprint, and the sides of the U are two narrow nearly-dry areas which are present both below and above aquaplaning (or penetration) speed. These seem to correspond with previously known areas of maximum pressure measured in static tyre tests, and they arise apparently from wall stiffness. It is thus not surprising that the water is squeezed out most completely in these areas, and the effect can be seen under oblique lighting where the areas reflect; they are close to the side limits of the footprint, extend for much of its length, and the rear half only of this pattern is visible in Fig.4.

The U-contact is shown clearly in Fig.3, where the thickness of "water" (10% condensed milk added) under the tyre can be assessed from a milk wedge scale photographed alongisde on the same negative; the comparable static footprint reveals the contact area that has been lost. In this test the rolling r.p.m. were only about 25% of full rolling, but this affects the pattern very little.

The directions and velocities of flow under and around the tyre, for nearly the same conditions as the milk photograph, but for the fully rolling condition which is the one met with on the Meteor when entering the water, are given in Fig.6. The polythene particles trapped in the sides of the U show full free-stream velocity, whereas the flow down the middle is slowed down considerably; so on the runway the water under the middle is carried forward at something like 1/3 of the aircraft speed. It will not therefore develop the full hydrodynamic stagnation pressure as assumed by NASA, but will approximate more to the tyre pressure. Cavitation points can be seen near the start of the U. Fig.5 gives a static footprint to the same scale as Figs.6, 7 and 8. The apparent wide nose shape of the tyre in Figs.6-9 is due to the optical effect of the water.

The flow patterns at 30 ft/sec, before "penetration" has begun, are shown in Figs.7 and 8 for the fully rolling and locked cases. In rolling the stagnation region at the nose can be seen, also trapped particles moving at full speed (particle streaks are shorter at 30 ft/sec than at 50 ft/sec); in the locked case, the trapped particles (about 1/200" dia.) are stationary.

The flow pattern for the locked wheel in the 50 ft/sec case, to compare with Fig.6, is shown in Fig.9. The trapped particles in the U contact area are stationary while the flow down the middle is still more than half free-stream speed. Free-stream speed can be seen from particles in the surrounding liquid or in the band of light caused by a line-joint in the drum and cutting across the picutre. Towards the base of the U it is seen that the flow slows down and then spreads fanwise; this corresponds to the thicker milk in Fig.3. As it escapes into the cavitation region behind the U it is seen to regain much velocity. Two large cavitation regions are seen on either side of the U also.

6 FURTHER WORK

It is intended to test a "block pattern" tyre on the Meteor to compare with the results of Fig.1. It is also intended to replace the small plasticine ridges with rows of small "pimples" of plasticine, to be quite sure that the 1 mm and 1/10 in. ridges did not affect the flow under the Meteor tyre.

7 CONCLUSION

It is thought that a fair general picture of the phenomenon has been obtained, and that a good part of our effort should now be turned to seeking remedies for aquaplaning.

8 ACKNOWLEDGEMENT

Acknowledgement is due to A. C. Browning and D. J. Nosworthy for much help with the model tests.

REFERENCE

1 F.A.A. and N.A.S.A. Joint Technical Conference on Slush Drag and Braking problems. Dec. 19-20th, 1961.

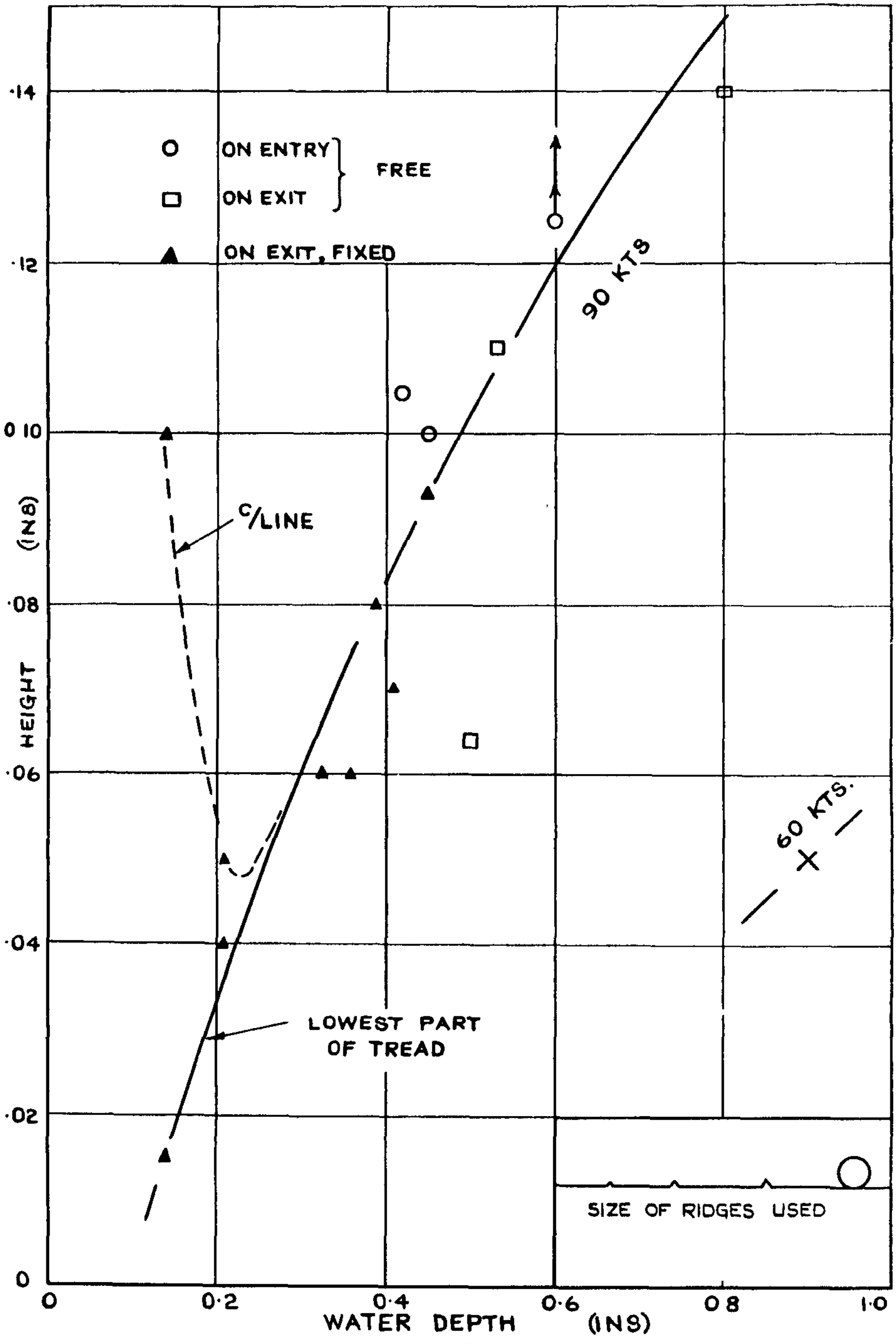


FIG. I. "AQUAPLANING HEIGHT" OF METEOR TYRE FROM RUNWAY, AT 90 KNOTS (RIBBED, 2 TON LOAD)

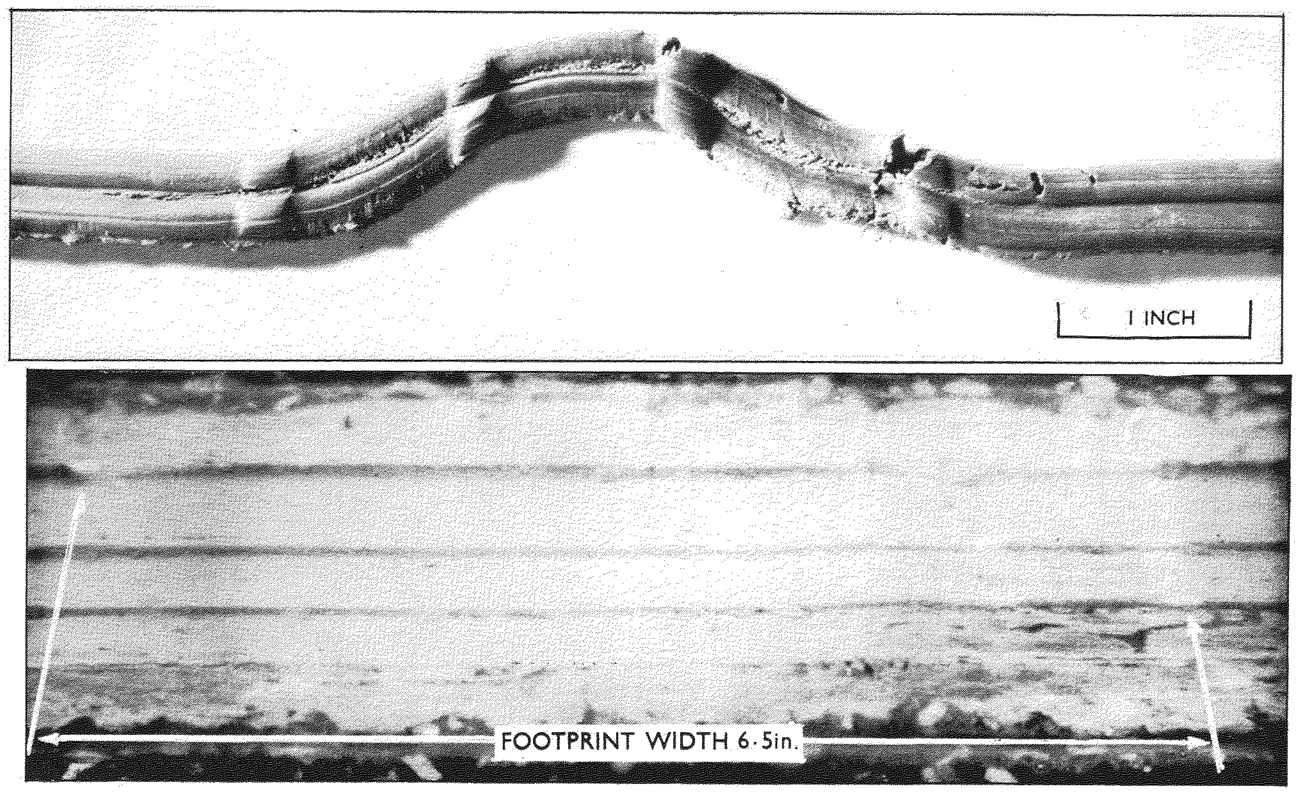
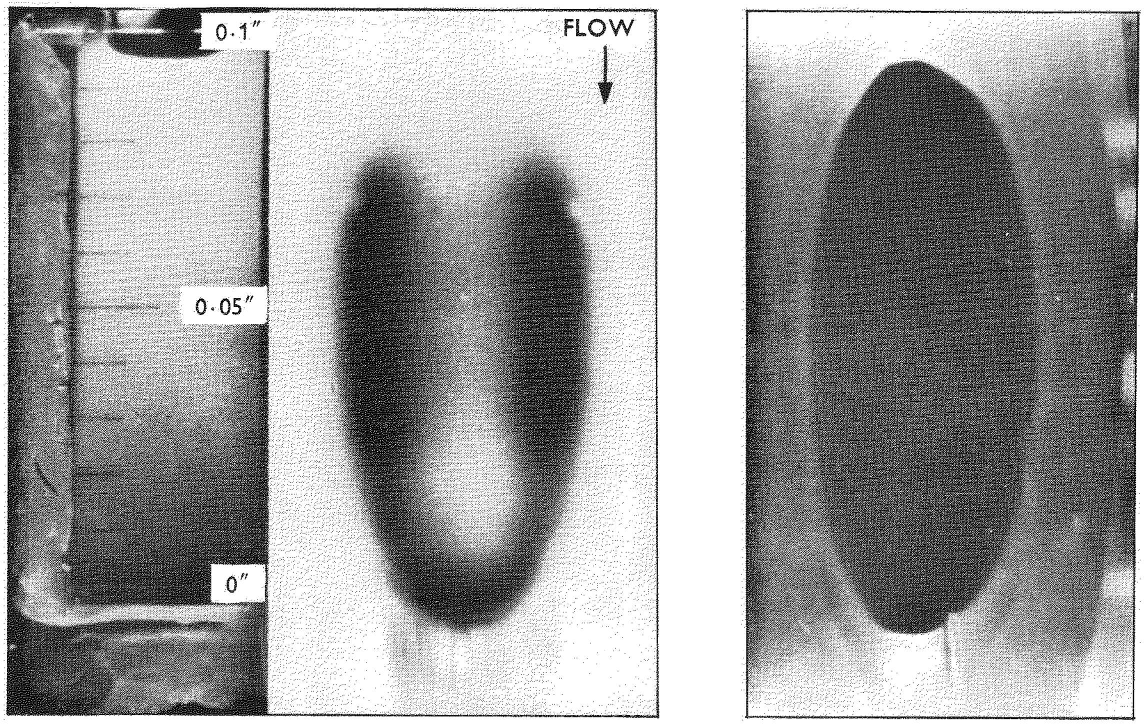


FIG.2. PLASTICINE STRAND, AND FIXED TRIPLE RIDGE, AFTER METEOR TESTS



MILK SCALE FOOTPRINT STATIC

FIG.3. LIQUID THICKNESS, MODEL AT 50 ft./sec., 1/16th in. DEEP. (75% SLIP)

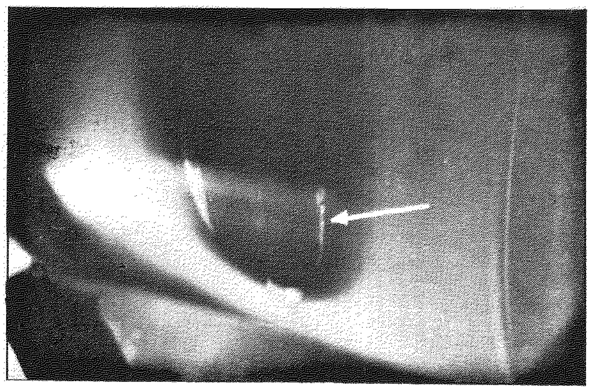


FIG.4. NEAR-DRY AREAS AT 30 ft./sec. IN 1/16th in. MILK, LOCKED

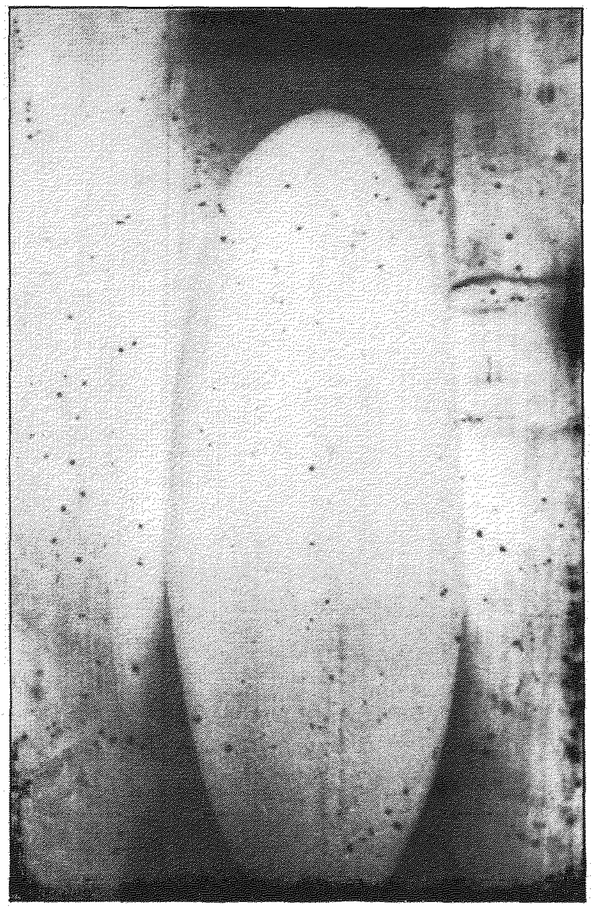


FIG.5. STATIC FOOTPRINT

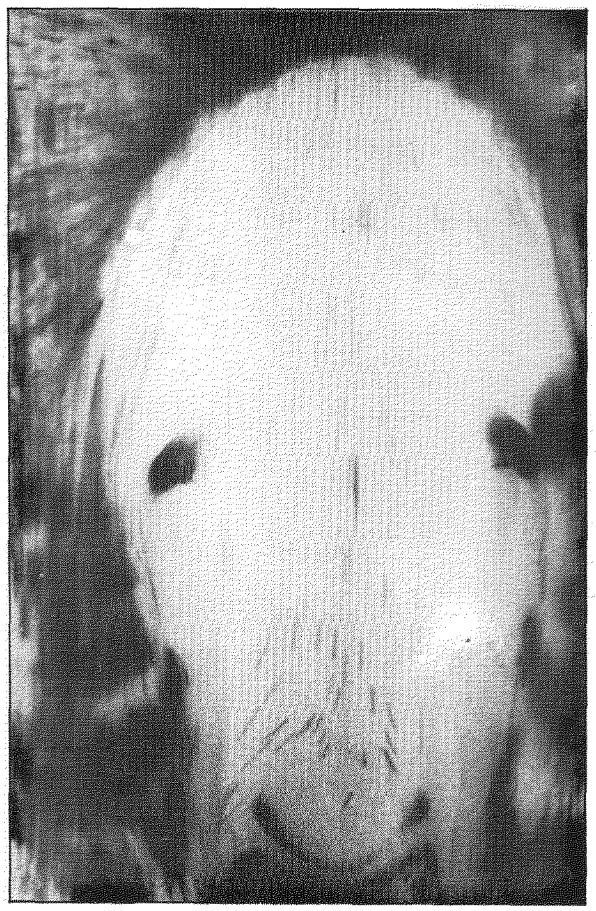


FIG.6. FULL ROLLING 50 ft/sec., 1/16th in.

FIG.7. FULL ROLLING 30 ft/sec., 1/16th in.

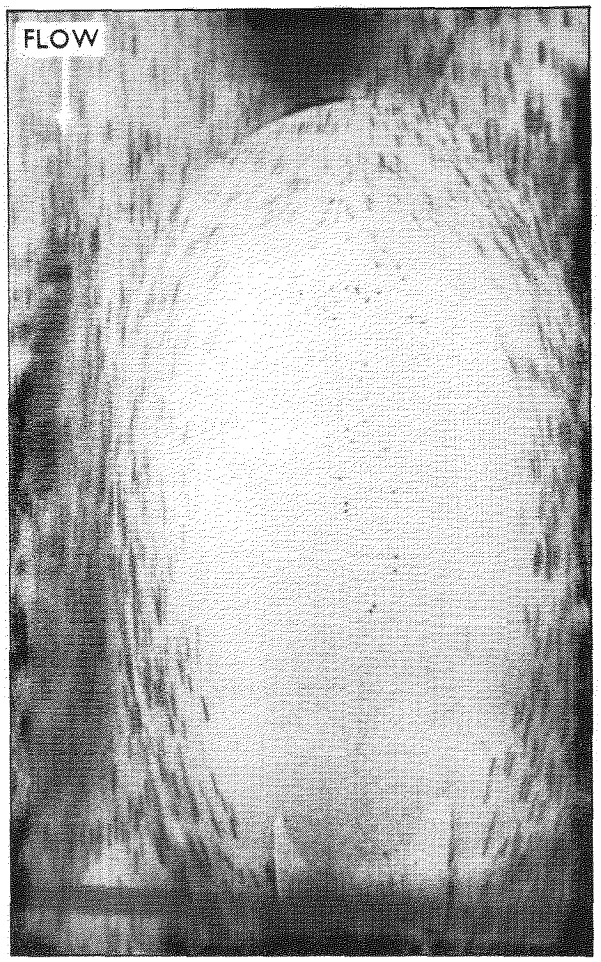


FIG.8. LOCKED 30 ft/sec., 1/16th in.

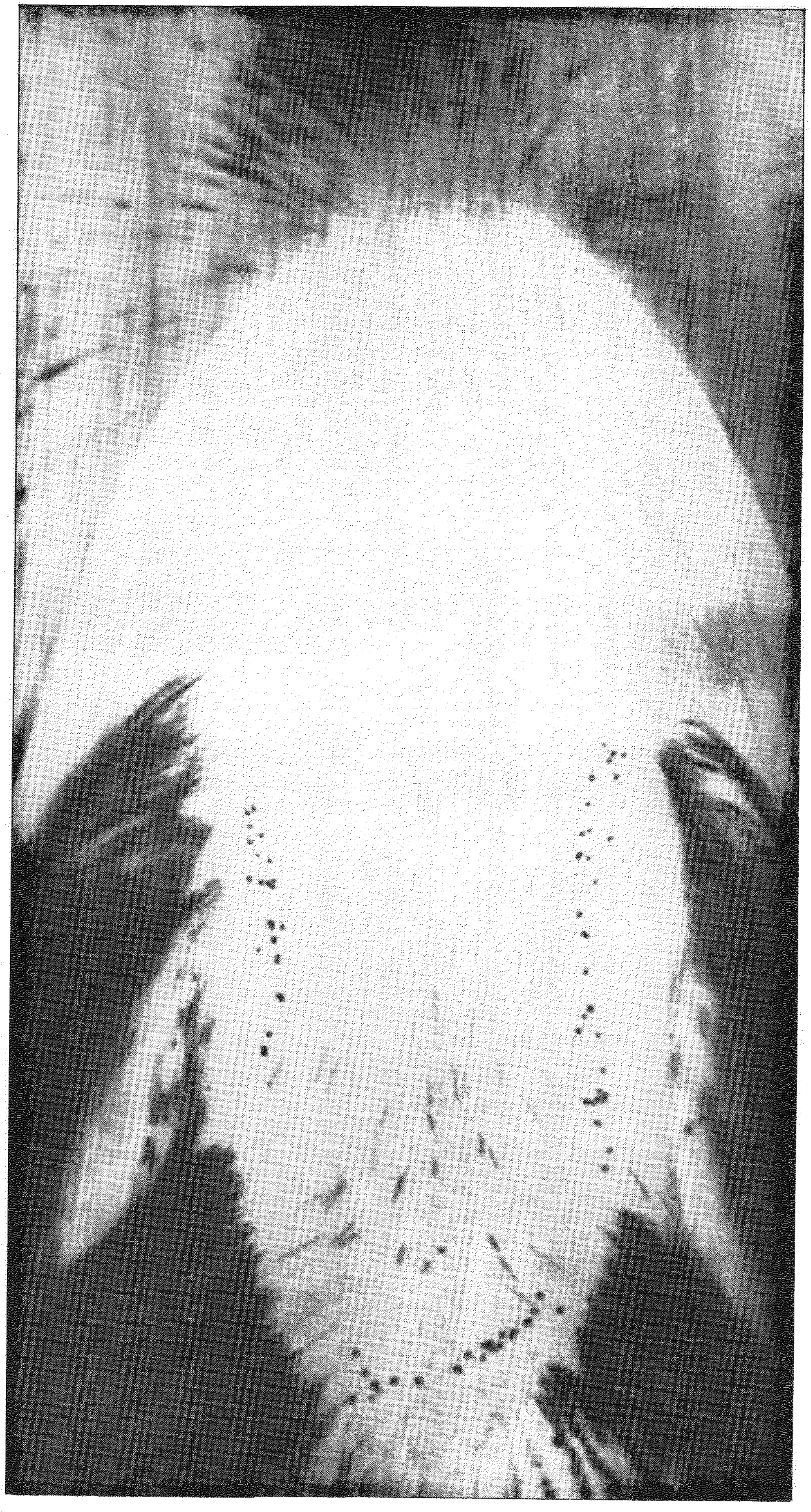


FIG.9. LOCKED MODEL WHEEL AT 50 ft/sec.
WATER AND ACETONE (50/50) 1/16th in. DEEP
VELOCITIES SHOWN BY PARTICLE MOVEMENT

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