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A FACILITY FOR WAVE RIDING RESEARCH

P.D. KILLEN AND R.J. STALKER

DEPARTMENT OF MECHANICAL ENGINEERING

UNIVERSITY OF QUEENSLAND, ST. LUCIA, QLD. 4067 AUSTRALIA

SUMMARY Previous experiments have established the feasibility of using a recirculating facility to produce a stationary, oblique breaking wave for the investigation of wave riding dynamics. Following extensive model studies a facility was constructed which will produce an 0.8 m high wave. Comparisons of model and full-scale operating characteristics indicate that the model was a succssful representation of the full-scale and may be used for investigating proposed improvements to the full-scale facility.

1 INTRODUCTION

Surfboard riding is a substantial and developing recreational industry but, unlike some other recreational industries, it has only recently begun to receive scientific attention. Such attention has been encouraged not only by the fact that surfboard riders, using a relatively simple planing craft, have established mastery over a difficult environment, but also by the history of surfboard development. New ideas, relating particularly to changes in surfboard configuration, have generally required an extensive period of trial and retrial before their advantages can be established, and they can be incorporated into general use. Given the inconsistency and variability of the sea environment in which surfboards are tested, this is hardly surprising. It is clearly difficult to determine whether a design change has effected an overall improvement in the riding qualities of a surfboard, when tests are conducted in an environment where the variations from one wave to the next may mask the effect of board improvements.

There is therefore a need for development of a facility in which a breaking wave, of the type favoured by surfboard riders, can be produced in a consistently repeatable manner. An initial experimental study of surfboard wave riding (Hornung and Killen, 1976) has established the feasbility of working with a stationary breaking wave. Since this offers considerable advantages in allowing long test times, pressure measurement and flow visualization, it was decided to develop a facility in which a stationary breaking wave would be produced in a recirculating flume.

The experiments performed by Hornung and Killen were conducted at a scale such that surface tension effects could significantly influence flow details and a laminar boundary layer, rather than the turbulent boundary layer on the full-scale surfboard would be expected. Also facility induced surface waves, including capillary waves, were sufficient to make pressure plotting impossible. It was therefore decided to design and construct a facility with a larger wave which would be free of these undesirable effects.

An initial one-twelfth scale model study of this facility has been reported in a previous paper. (Killen, 1980). The present paper covers further testing of the model facility, aimed at producing an optimum design, and compares the operation of the one-twelfth scale model with that of the full-scale facility.

2 POWER REQUIREMENTS

The power requirement to operate a recirculating facility will depend on the wave height, channel width and depth required at the test section. Channel width should be about five times the height of the wave face so that the behaviour of the model surfboards can be studied over a suitable range of wave surface curvature and steepness. The channel depth must be such that the clearance between the surface of the wave making obstacle and the surfboard hull, when the board is riding on the wave, is sufficient to avoid effects similar to the "ground effect" experienced with very low flying aircraft or the proximity of a wall in wind tunnel testing (e.g. enhanced lift and drag coefficients and increased lift/drag ratio caused by the change in flow direction near the stationary boundary).

In order to obtain an approximate theoretical prediction of the required clearance the flow at the surfboard is represented by two vortices originating at the same point and growing equally in streanth as they pass downstream. It can then be shown that, if the depth of the water is equal to the surfboard beam, then proportional changes in lift and drag of the board, arising from the proximity of the obstacle surface, are small. (i.e. of the order of 10% or less).

Given that a modern surfboard has a beam of approximately 0.5 metres, and that the need for turbulent boundary flow on models of surfboards demands a model scale of at least one-third of full size, it follows that the water depth at the wave face should be at least 0.17 m. The flow studies in the facility model study showed that this requires a depth of $\geq$ 0.15 m in the test section flow approaching the wave obstacle.

For surfboard models of one-third to one-half scale a representative wave height is $\approx$ 0.8 m. The power required to produce this wave may be calculated according to the procedure outlined by Killen (1980) and is

$$P_{ts} \geq 15.0 \text{ kW}.$$

3 THE FACILITY CONFIGURATION

The facility layout is shown in planview in Figure 1. The one-twelfth scale model was constructed of galvanised sheet steel. The test section bottom, wave producing obstacle and inlet to the pumping section were formed in plasticene for ease of alteration. Two plastic model boat propellers, driven by variac controlled electric motors, pumped water through a mixing section and diffuser to a sluice gate which controlled the flow into the wave-producing obstacle. The downstream end of this obstacle was shaped as a turning vane so that the combination of obstacle and turning vane produced a one hundred and eighty degree turn and so directed the flow into the mixing section. It was necessary to avoid choking of the flow downstream from the obstacle and turning vane as choking prevented the development of a satisfactory steady flow over the obstacle. It was found that this could be done by allowing the bottom of the channel to fall away at a rate sufficient to maintain supercritical flow

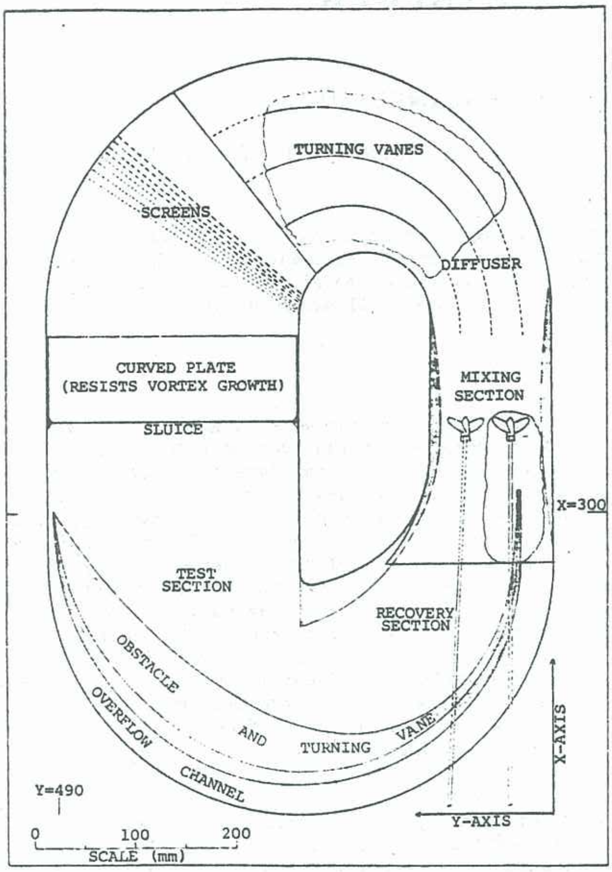

Figure 1 Planview of one-twelfth scale model

4 OPERATIONAL CHARACTERISTICS

4.1 Initial Formation of the Wave

As may be imagined, there will be a transition period between the starting of the facility and the formation of a steady breading wave. Initially the entire flow will be subcritical. However as momentum is transferred to the flow there will be a small region downstream from the sluice gate which is supercritical. This region gradually extends downstream to the obstacle and the curl of the wave begins to form at the upstream end of the obstacle. At this stage, the remainder of the flow along the obstacle is a turbulent hydraulic jump and the flow entering the mixing section is also very turbulent and subcritical. As the wave begins to form the velocity of this flow increases dramatically and this causes an increase in efficiency of the propellers which in turn increases the height of the water built up behind the sluice.

The increase in head provides for increases in both velocity and discharge of the flow into the test section, and, if the increase in velocity is of sufficient magnitude, then a fully developed breaking wave is formed. The formation of the wave then clears any remaining subscritical flow from the test section and produces supercritical flow in the recovery section.

4.2 Influence of Fill Level on Opeararation

Since the full scale facility was to operate as a closed system, with no reservoir or other provision for the addition or removal of water during operation, it was realized that the volume of water present at starting might have a significant effect on operation and particularly on the power required to generate a wave.

Accordingly an investigation was undertaken to determine the influence of the fill level (measureed as height above the datum which was at the lowest point of the mixing section floor).

The propellers used in this investigation were 2 blade 27.5 mm dia. plastic propellers with a pitch/diameter ratio of ≈ 0.81 and an expanded blade area ratio of 0.43. The procedure adopted was as follows;

The sluice was set at a particular opening (either 9 mm or 14 mm) and the angular velocity of the propellers held constant while the facility was slowly filled. (It was decided that maintaining constant angular velocity was much easier than maintaining constant power input from the propellers because the duration of each test was sufficient for the shaft bearing resistance to change significantly, > 10%. In addition, it was determined that the propeller power loading varied only ± 5% over the operating range).

At fill levels below that required for the production of a wave, the flow in the test section was choked by an hydraulic jump and the flow in the recovery section, leading to the propellers, was very turbulent and subcritical. However, as the fill level was increased, the head produced at the sluice also increased, and as the fill level reached that required for operation, the starting process described above was observed. At the first indication of a wave forming, the hose supplying water to the model was removed. Within five seconds, a steady state operating level was established. Attempts were made to determine the total head produced at the sluice at the initial moment of formation of the wave, and again, once steady state operation had been attained. This was only partially successful due largely to the transient nature of the starting process. Determination of the fill level was made by turning off the motors and measuring the free surface height (above the datum) of the stationary water with a probe. This had to be done quickly and was subject to some error (≈1 mm), as the holes in the side walls through which the propeller shafts passed were below the still water level and leaked considerably when the model was not operating. Fortunately, the discharge through these holes was reduced substantially once a wave had been formed.

Once a minimum fill level for self starting operation had been obtained, the model was filled to successively higher levels during operation, the total head produced at the sluice recorded and the motors switched off so that the fill level could be recorded. This process was continued until the fill level reached the maximum which would allos for self starting operation. From this point on there was some difficulty involved in obtaining data as the head produced at the sluice was not necessarily proportional to the fill level. In order to obtain data, the model was filled to the maximum level which would allow self-starting and, once a wave had formed, filled further. The head produced at the sluice was measured, the motors were then switched off and the fill level recorded. Measurements continued in this manner until a maximum operating fill level had been established. This fill level was usually characterised by a reduction in the total head produced at the sluice and also by choking of the flow in the recovery section. The increased surface height in the recovery section then allowed this disturbance to propagate upstream to the wave, causing a breakdown of the smooth plunging wave into an oblique hydraulic jump, and ultimately, a normal hydraulic jump which completely choked the test section. In appearance this process was the reverse of the starting process.

In order to determine the maximum fill level for self-starting operation, the model was filled to above the maximum operating fill level while the motors were running and, as water slowly leaked out to the appropriate level, the familiar process of wave formation began. As before, attempts were made to determine the steady state and transient total head produced at the sluice and, as before, there was mixed success.

In order to determine the minimum operating fill level, the reverse of the procedure for obtaining the maximum fill level was used. The minimum fill level was reached when the wave collapsed near the upstream end of the obstacle. In this manner, operating characteristics were obtained for a range of angular velocities of the propellers. The results are presented in figure 2 as plots of power in the flow in the test section(P_{ts}) vs fill level for various angular velocities and sluice openings of 9 and 14 mm. The solid portion of each curve indicates the range of fill levels for which the facility was self-starting. The vertical bars connect the initial (transient) and operational values of P_{ts} which were obtained in some cases. The numbers in parentheses indicate the average value (over the self-starting region) of the total power required to drive the propellers.

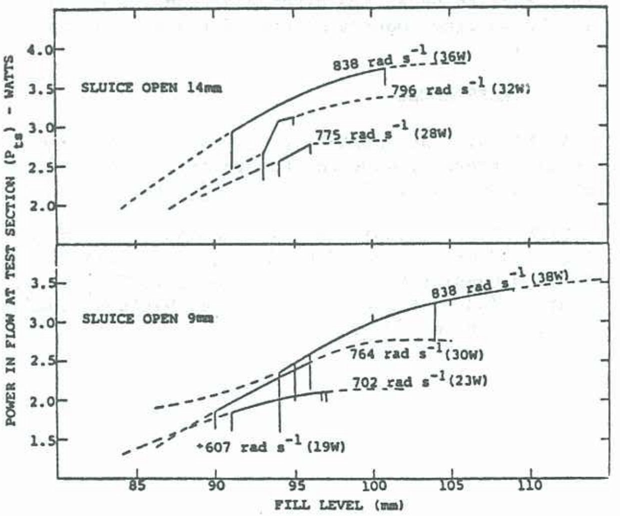

Figure 2 Influence of fill level on dynamic performance

In general, the plots show;

(i) increases in P_{ts} with increases in fill level within the self-starting operating range. This is to be expected as the propellers will operate more efficiently as the fill level increases and reduces their tendency to ventilate.

(ii) increases in P_{ts} with increases in angular velocity of the propellers for constant fill level.

(iii) increases in P_{ts} with increases in sluice opening. This will only necessarily be true within the operating range as there is a sudden decrease in P_{ts} as the operating range is exceeded and the test section becomes choked. Note that, within the operating range, the increase in P_{ts} with sluice opening is the result of an increase in cross-section of the flow which increases the discharge and masks the effects of the decrease in thrust at the sluice (i.e. reduced head at the sluice). This decrease in thrust with increased discharge is to be expected in the pumping systems.

(iv) an increase in operating range with increases in the angular velocity of, and hence power supplied by, the propellers for a particular sluice opening.

(v) decreases in the range of fill levels and angular velocities of the propellers over which the facility operates, with increases in sluice opening.

(vi) A minimum value of P_{ts} below which the facility will not operate, regardless of fill level.

5 OPERATION OF THE FULL-SCALE FACILITY

The shaft power required for operation of the full-scale facility may be estimated from fig. 2 although of course, it may reasonably be expected that there will be some variation from these scaled values caused by changes in Reynolds and cavitation numbers.

Recirculation in the full-scale facility was provided by two 105 hP (≈ 80 kW) Chrysler outboard motors. This meant that unless there was an increase in efficiency from model to full-scale, then it would not be possible to achieve self-starting operation at sluice openings equivalent to 14 mm since the scale equivalent of 28 W is ≈ 168 kW. (The sluice opening may be expressed as a percentage of the test section width. Thus, 14 mm ≡ 5.6% and 9 mm ≡ 3.6%).

Fortunately, there was a very significant increase in propulsive efficiency, > 24%, and it was possible, given suitable propellers and appropriate fill levels, to achieve self-starting at a sluice openings up to 5.6%.

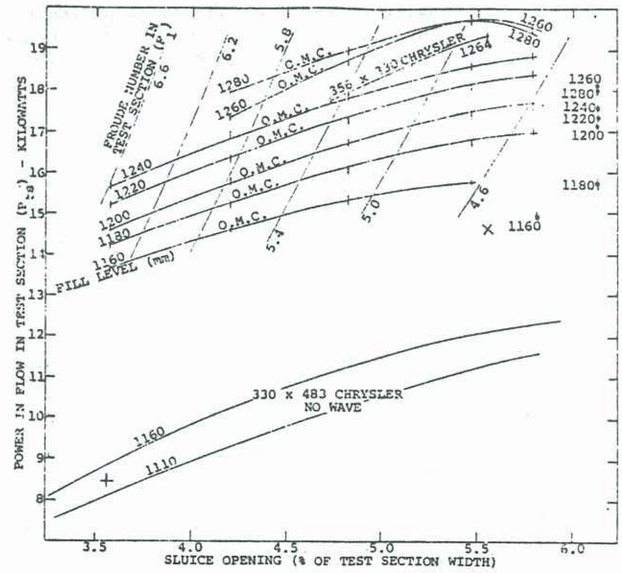

Figure 3 Operating Characteristics of the full-scale facility

Figure 3 shows the operating characteristics of the full scale facility. In this figure, P_{ts} is plotted as a function of sluice opening rather than fill level since sluice opening was more easy to vary than was the fill level. The curves were obtained using three different propellers which were tried in an attempt to determine a propeller size and shape best suited to both the flow conditions and the motor characteristics. The propellers were:

(i) 300 mm dia x 483 mm pitch, Chrysler - these were overpitched for this application

(ii) 356 mm dia x 330 mm pitch, Chrysler - these were better suited but suffered from vibration which caused a blade to break off one of the propellers.

(iii) 356 mm dia x 229 mm pitch, Outboard Motor Corporation (O.M.C.) - these were even better suited and did not appear to suffer the same vibration problems. However, the motors were still not able to run at their optimum speed.

The broken lines indicate the Froude number of the flow in the test section (F). It can be seen that as the fill level is decreased it is possible to operate at lower value of F and hence significantly different shaped waves from those obtained with greater fill levels. However, there is a practical limit to this process - as indicated by the reduced sluice opening for which a wave would form at a fill level of 1160 mm. The curves also indicate that there exists a maximum operating fill level. Note the crossing-over, at a sluice opening of 5.4%, of the O.M.C. curves for fill levels of 1260 and 1280 mm. Data was also obtained for the O.M.C. propeller for sluice openings greater than those for which a wave could be sustained. In these cases a substantial reduction in P_{ts} was observed which was similar to that experienced with the model. These points are marked with a dot and a number which indicates the fill level.

The two crosses indicate the predicted minimum operating values of P_{ts} (based on the model studies) for sluice openings of 3.6% and 5.6%.

In the case of the 330 x 483 Chrysler propellers no wave was formed although the flow produced at 3.6% sluice opening was characteristic of that produced when a wave was beginning to form. However, as these propellers were used before the installation of the turbulence-reducing screens, in the stilling region upstream from the sluice the flow in the test section was very turbulent and a stable wave would not form.

At a sluice opening of 5.6%, starting occurred at a power level slightly in excess of the predicted value, with a slightly higher fill leve, but it failed to start when the sluice opening was increased slightly. At all sluice openings, the test-section power increased with fill level (up to 1260 mm) thus following the trends exhibited in the model.

6 CONCLUSION

The successful prediction of the critical starting conditions, as well as observed qualitative similarity between flow patterns in the model and full-scale facility in both the started and unstarted modes, provided reassurance that the general fluid dynamics of the full-scale facility were well represented by the model.

Although the facility has not yet operated at the required flow depth for model surfboard studies, the establishment of the efficiency increase associated with the scaling up process enables more accurate predictions of the power requirements of the full-scale facility to be made. Further studies into the effects of sluice opening and obstacle shape have indicated that the efficiency increase will allow for operation of sluice openings up to 9.9% (306 mm) which will provide for depths of up to 187 mm in the test section once some minor additions have been made to the leading (upstream) end of the wave producing obstacle.

7 REFERENCES

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