A further note on the speed of floating bodies in a stream

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In an earlier contribution (Francis 1956), a report was made of the speed of small solid bodies floating in the upper layers of a free surface stream. The bodies were cylinders of several diameters floating with their axes vertical and ballasted to the same draft. All the floats travelled at the same speed in the long, wide stream which was of constant depth and was strongly sheared, and this speed was the mean speed of the upper layers of the stream. It was pointed out that this result is unexpected, since the solid boundaries of the floats prevent turbulent interchange there, so that the floats are not locked to the stream in the same way as the corresponding volume of turbulent water would be locked. Thus the floats would be expected to travel a little faster than the stream, large diameter floats travelling faster than small floats.

This contradiction led Prof. Hellström to send a photograph of a log of wood floating down a steeply sloping channel. There seems to be a clearly defined bow-wave as the log moves downward relative to the water. The question therefore arises as to the difference between the log and the floats used in the laboratory experiment.

A possible reason for the difference may be that the laboratory floats were never more than 6·3 cm diameter, and were floating in a stream of depth 7·5 cm, and so were still not very large in horizontal extent compared to the depth. The shear in the laboratory channel was developed largely by secondary current systems from regular roughness elements, so that the effective size of the momentum transporting systems was of the order of the depth and was large compared to the floats. Thus these small floats did not materially affect the turbulence in the stream, and so were restrained in the same way as the corresponding mass of water would be restrained.

On the above hypothesis, it seems necessary to have a float which is large in horizontal extent compared to the depth of water under it if the turbulence is to be modified and the float allowed to travel faster than the water. The float should still be appreciably smaller than the width of the channel to avoid side effects, and the channel must have efficient roughness on the bottom in order to give a large shear and so a large surface gradient.

An experiment has been conducted in order to see if very large floats travel faster than smaller ones of the same draft. A steel channel, 76 cm wide and 6·7 m long, had wooden battens 2·5 cm wide by 4 cm high, placed across the bottom, with clear spaces 5·4 cm between them. The channel could be tilted until the bed was parallel to the surface of the water. A discharge of 0·0101 $\mathrm{m}^3\,\mathrm{sec}^{-1}$ was made to flow down it, and it was found that a slope of 1/161 gave a uniform depth of 3·8 cm above the tops of the wooden battens all along the channel. Three wooden floats were used, the 6·3 and 1·9 cm diameter ones from the 1956 experiments and a new one 30·4 cm diameter. All three were ballasted to float to a 2·5 cm draft, but only an insignificant part projected into the air. Thus the new one was a cylinder of a length/diameter ratio of only 1/12.

The floats were timed over a 3·86 m test length of channel starting 1·9 m from the inlet and ending 1·0 m upstream of the outlet. Any drift in which the float came within 7 cm of the walls of the channel was neglected. The timing was by stopwatch calibrated to 1/100 sec, and the times are shown in table 1.

It will be seen that the largest float travelled faster and more consistently than the smaller floats. The slowest timing of the largest float was faster than the fastest timing of either of the others.

Float diam. (cm.)	30·4	6·3	1·9
Number of successful drifts	20	20	20
Mean time to traverse 3·86 m (sec)	8·01	8·82	8·89
Mean deviation (sec)	± 0·07	± 0·16	± 0·23
Mean speed (m/sec)	0·482	0·438	0·435

TABLE 1. Measured velocities of cylinders 2·5 cm long drifting in a stream 3·8 cm deep.

The largest float was also tested to find at what speed it would travel in still water if towed with a pull of 1/161 of its weight: this proved to be 20·5 cm/sec. Perhaps if this float had modified the turbulence in the water under it so completely that the stress there was zero, then it would travel 20·5 cm/sec faster than small floats. A float to do this would, of course, be nearly infinite in extent; the 30·4 cm diameter float was not large enough to modify all turbulence completely as it passed over so it only travelled some 4 cm/sec faster than the mean speed of the layer of water in which it floated. In fact, it travelled at approximately 1 cm/sec faster than the surface speed of the water, as shown by the relative motion of aluminium dust sprinkled on the water.

Another experiment carried out in the same channel confirms this observation. Cylindrical cup-like floats were made from 1 mm thick Perspex (methyl methycrylate) sheet, having only one end of the cylinder closed by a circular disk. One float was 30·4 cm diameter and 2·5 cm long, and two others were 2·5 cm diameter and 2·5 cm long. The large float was arranged to float full of water with its solid Perspex diaphragm uppermost and level with the water surface, buoyancy being provided by small pieces of a foam plastic fixed to the rim; the water within the float was therefore free to interchange with the rest of the water in the channel. The speed of this float was compared with that of the previous 30·4 cm float, made of wood and ballasted to the same depth. The two smaller Perspex floats were ballasted to float to the same 2·5 cm draft but one was arranged to float with the diaphragm uppermost, and the other with its diaphragm below. The former allowed interchange of fluid within it, and the latter did not allow interchange.

The flow in the 76 cm wide channel was now 0·0171 $m^3 sec^{-1}$ and a slope of 1:182 was found to give a uniform depth of 5·2 cm above the wooden battens. The floats were timed over a 2·40 m test length, and the times of ten successful drifts were taken of each float. These results are shown in table 2.

It is clear that although the solid wooden float *A* travels faster than the large open bottomed Perspex float *B*, both the two small floats travel at the same speed. Thus it appears that the solid lower end of the small float *C* is not sufficiently large to affect the turbulent fluctuations responsible for the interchange of momentum at these levels in the stream. So floats *C* and *D*, one allowing interchange by small-scale fluctuations only and the other allowing no interchange at all, both travel at the same speed with neither float modifying the large-scale fluctuations. Floats *A* and *B* travel at different speeds because *B* can accept large-scale fluctuations and *A* cannot. So *A* modifies the large fluctuations, while *B* does not and so moves at the same speed as *C* and *D*.

	A	*B*	*C*	*D*
Float diam. (cm)	30·4	30·4	2·5	2·5
Type of float	Wood	Perspex diaph. uppermost	Perspex diaph. downward	Perspex diaph. uppermost
No. of successful drifts	10	10	10	10
Mean time to traverse 2·40 m (sec)	3·84	4·51	4·47	4·46
Mean speed m/sec	0·625	0·532	0·538	0·537

TABLE 2. Measured velocities of cylinders drifting in a 5·2 cm depth stream.

Thus it appears that floats can only travel faster than the water they sample if they are large compared to the scale of the turbulent fluctuations transporting momentum downwards in the stream. The log of Prof. Hellström's photograph is large compared to the depth of water and so can travel relative to the stream. Prandtl's (1952, p. 179) statement that ships drifting in rivers 'hurry ahead of the water' may therefore be true only if an important qualification is made: that the ship is of large horizontal extent compared to the depth of water under it, so that it greatly modifies the flow in its neighbourhood.

The experiments described above were carried out in the Civil Engineering Laboratories of Imperial College.

REFERENCES

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