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Subjects 2 and 4 - Skin Friction and Turbulence Stimulation

Contribution by Professor M. Yamagata

The coefficient of frictional resistance for transitional flow along a smooth flat plate are generally represented by the expression

$$C_f = C_{ft} - \frac{R_n'}{R_n}(C_{ft}' - C_{f\ell}') = C_{ft} - \frac{K}{R_n},$$

where R_n and R_n' are Reynolds numbers, referred to the length of the plate and of laminar region, respectively,

C_{ft} is the coefficient of frictional resistance for turbulent flow, taken at R_n,

C_{ft}' and $C_{f\ell}'$ are the coefficients of frictional resistances for turbulent and laminar flows, taken at R_n', respectively,

and K depends on R_n', being equal to $R_n'(C_{ft}' - C_{f\ell}')$.

Prandtl chose a value 1,700 for K to give agreement with Blasius' and Gebers' results of resistance measurements with flat rectangular plates, which was derived from $R_n' = 0.485 \times 10^6$. These values correspond to a comparatively late transition to turbulence, namely, the transition curve most likely to occur when the plate itself caused little disturbance, and moved into quite undisturbed fluid. But Goldstein obtained later the critical Reynolds numbers up to 1.1×10^6 at wind-tunnel experiments.

The results of detecting chemically the laminar and turbulent extents over flat rectangular plates, made at the Experiment Tank of the University of Tokyo, showed clearly the serious effects of the longitudinal edges of plates and free surface upon the flow pattern over plates. As seen in the schematic sketches of Fig.1, the laminar extent is not rectangular against our expectation, and, within these experimental results, it has always the shape of a horizontal wedge, consisting of two approximately straight lines, starting from the fore part of the plate and making an angle of about 10° to horizontal. Of course, at higher velocity or larger draught (or depth) of a plate, a vertical line may be expected as the aftermost boundary of laminar region, from which the critical Reynolds number free from longitudinal edge and free surface effects will be obtained. Fig. 2 shows some examples of such vertical boundary lines, though very irregular saw-teeth shaped, measured with another rectangular plate, which would be supposed to occur at comparatively low Reynolds numbers probably due to the worse shape of its leading edge.

Thus, it may be said that, besides the degree of initial turbulence of the fluid coming up to the plate and the unavoidable disturbance of leading edge of the plate, its draught (or depth) changes considerably the value of R_n', and accordingly the value of K. The former calculated, using the measured maximum length of the laminar region over the plate of 40.4cm draught at the velocity of 3m/s in the sketches of Fig.1, is about 2.9×10^6, which is much higher than Blasius' and Goldstein's values quoted above, but lower than 3.4×10^6 obtained by Schubauer and Skramstad in 1943 as $R_n^!$ of flat plates placed at zero incidence in the air flow of least initial turbulence. This endorses indirectly that the value of $R_n^!$ obtained above is affected by the longitudinal lower edge of the plate and the free surface of water.

It may be concluded that the remarkable effects of the longitudinal edge of a plate and the free surface of water on the laminar extent over a plate increase the frictional resistance for transitional flow with the increase of the ratio of its length to draught (or depth), i.e., its aspect ratio.

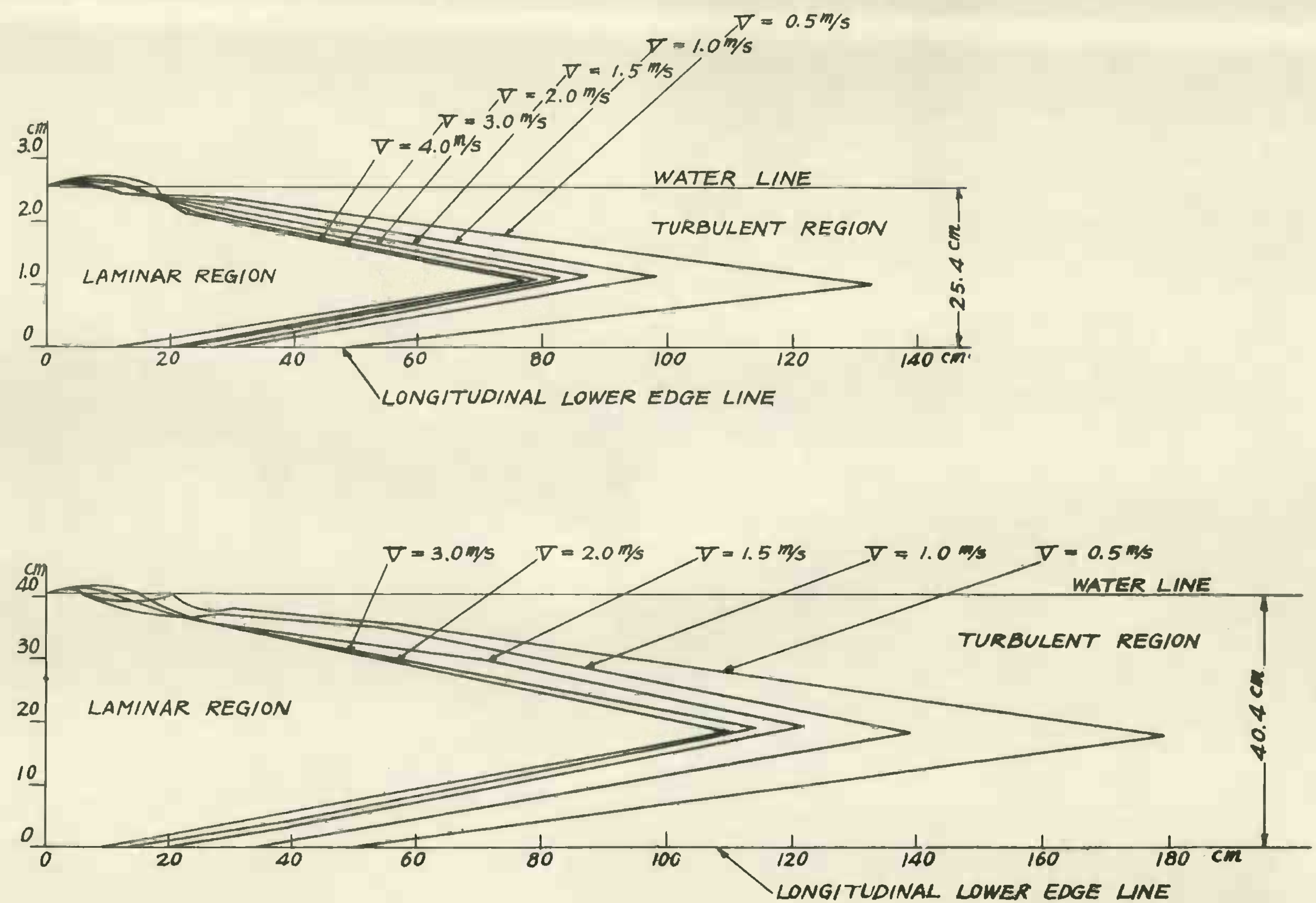
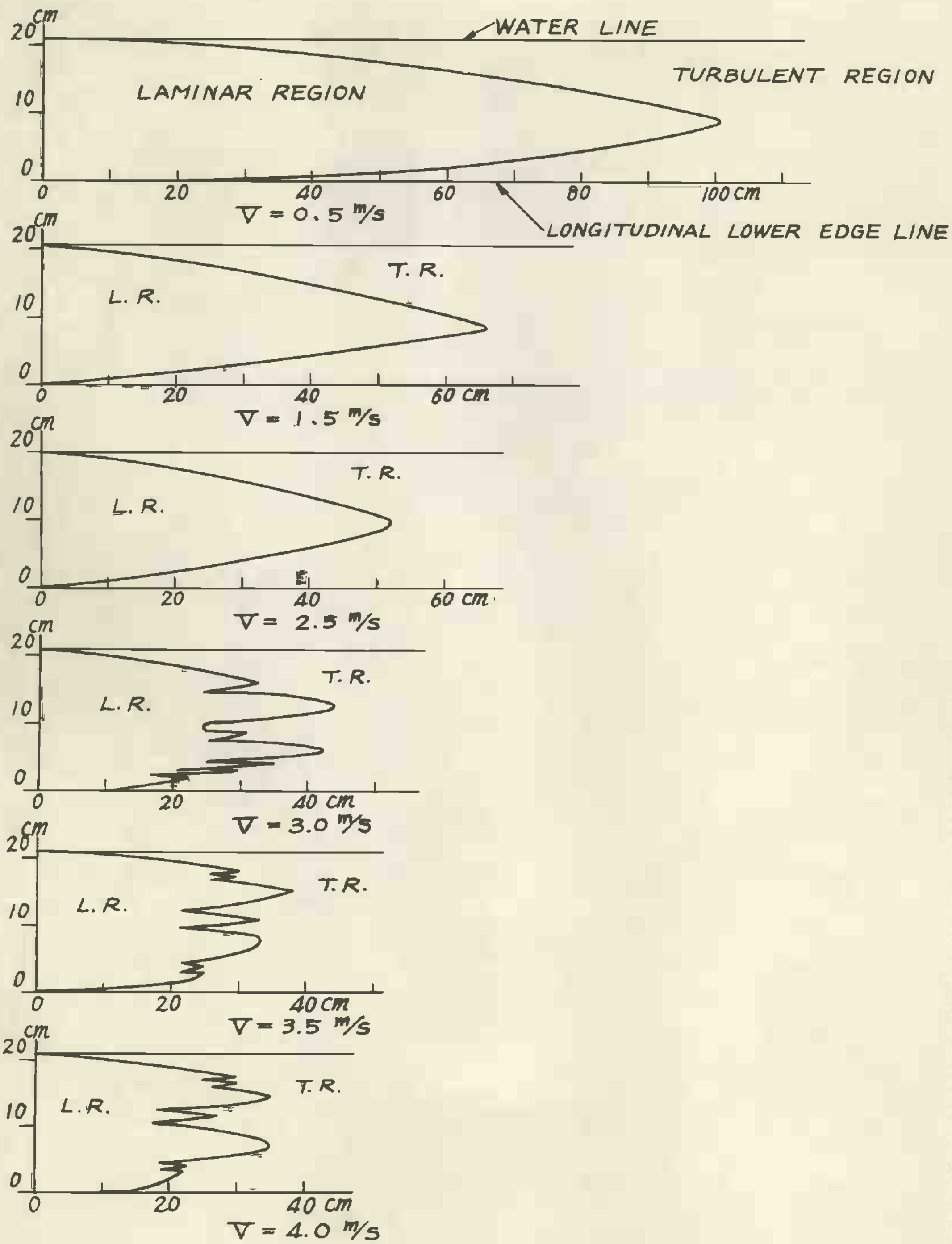

V = 0.5 m/s
V = 1.0 m/s
V = 1.5 m/s
V = 2.0 m/s
V = 3.0 m/s
V = 4.0 m/s
cm
3.0
2.0
1.0
0
WATER LINE
TURBULENT REGION
LAMINAR REGION
25.4 cm
0
20
40
60
80
100
120
140 cm
LONGITUDINAL LOWER EDGE LINE
V = 3.0 m/s
V = 2.0 m/s
V = 1.5 m/s
V = 1.0 m/s
V = 0.5 m/s
cm
40
30
20
10
0
WATER LINE
TURBULENT REGION
LAMINAR REGION
40.4 cm
0
20
40
60
80
100
120
140
160
180 cm
LONGITUDINAL LOWER EDGE LINE

Fig. 1.



WATER LINE
LAMINAR REGION
TURBULENT REGION
LONGITUDINAL LOWER EDGE LINE
V = 0.5 m/s
V = 1.5 m/s
V = 2.5 m/s
V = 3.0 m/s
V = 3.5 m/s
V = 4.0 m/s
L. R.
T. R.
cm

Fig. 2.