war will require about twelve times as much force to push her sideways as to push her head foremost. In this respect, therefore, she will very much resemble a chest whose length is twelve times its breadth ; and whatever be the proportion of these resistances in different ships, we may always sub­stitute a box which shall have the same resistances head­ways and sideways.

Let EFGH (fig. 1.) be the horizontal section of such a box, and AB its middle line, and C its centre. In what­ever direction this box

may chance to move, the

direction of the whole re­

sistance on its two sides

will pass through C. For

as the whole stream has

one inclination to the side

EF, the equivalent of the

equal impulses on every

part will be in a line perpendicular to the middle of EF. For the same reason, it will be in a line perpendicular to the mid­dle of FG. These perpendiculars must cross in C. Suppose a mast erected at C, and YC,y to be a yard hoisted on it carrying a sail. Let the yard be first conceived as braced right athwart at right angles to the keel, as represented by Y'y'. Then, whatever be the direction of the wind abaft this sail, it will impel the vessel in the direction CB. But if the sail has the oblique position Yy, the impulse will be in the direction CD perpendicular to CY, and will both push the vessel ahead and sideways : For the impulse CD is equiva­lent to the two impulses CK and CI (the sides of a rect­angle of which CD is the diagonal). The force CI pushes the vessel ahead, and CK pushes her sideways. She must therefore take some intermediate direction *ab,* such that the resistance of the water to the plane FG is to its resist­ance to the plane EF as CI to CK.

The angle *b*CB between the real course and the direction of the head is called the leeway ; and in the course of this dissertation we shall express it by the symbol *x.* It evidently depends on the shape of the vessel and on the position of the yard. An accurate knowledge of the quan­tity of leeway, corresponding to different circumstances of obliquity of impulse, extent of surface, &c. is of the ut­most importance in the practice of navigation ; and even an approximation is valuable. The subject is so very difficult that this must content us for the present.

Let V be the velocity of the ship in the direction *Cb,* and let the surfaces FG and FE be called A' and B'. Then the resistance to the lateral motion is mV’ χ B' × sine2, *b*CB, and that to the direct motion is mV’ × A'× sine2, bCK, or mV’ × A' ×cos2bCB. Therefore these resistances are in the proportion of B' × sine’, *x* to A' × cos.’, *x* (representing the angle of leeway bCB by the symbol *x).*

Therefore we have CI : CK, or CI : ID=A'∙cos.2x: B'∙

sine’\*, =A' : =A': B'∙ tangent2x.

cos.\*

Let the angle YCB, to which the yard is braced up, be called the trim of the sails, and expressed by the symbol *b.* This is the complement of the angle DCI. Now CI : ID=rad. : tan. DCI, =1 : tan. DCI, = hcotan. *b.* There­fore we have finally 1 : cotan. b=A' : B,∙ tan.2x, and A'∙

A,

cotan. *b=B'∙* tangent2x, and tan.2x= A'/B'cot. *b.* This equation evidently ascertains the mutual relation between the trim of the sails and the leeway, in every case where we can tell the proportion between the resistances to the direct and broadside motions of the ship, and where this proportion does not change by the obliquity of the course. Thus, sup­pose the yard braced up to an angle of 30° with the keel. Then cotan. 30o=1∙732 very nearly. Suppose also that the resistance sideways is twelve times greater than the resist­ance headways. This gives A'=l and B'=12. Therefore

1·732=12 × tangent2x, and tangent2x = 1·732/12, =0·14434,

and tan. \*=0∙3799, and \*=20’ 48', very nearly two points of leeway.

This computation, or rather the equation which gives room for it, supposes the resistances proportional to the squares of the sines of incidence. The experiments of the Academy of Paris, of which an abstract is given in the ar­ticle Resistance of Fluids, show that this supposition is not far from the truth when the angle of incidence is great. In the present case the angle of incidence on the front FG is about 70°, and the experiments just now mentioned, show that the real resistances exceed the theoretical ones only 1/150. But the angle of incidence on EF is only 20° 48'. Experiment shows that in this inclination the resistance is almost quadruple of the theoretical resistances. Therefore the lateral resistance is assumed much too small in the pre­sent instance. Therefore a much smaller leeway will suf­fice for producing a lateral resistance which will balance the lateral impulse CK, arising from the obliquity of the sail, viz. 30°. The matter of fact is, that a pretty good sailing ship, with her sails braced to this angle at a medium, will not make above five or six degrees leeway in smooth water and easy weather ; and yet in this situation the hull and rigging present a very great surface to the wind, in the most improper positions, so as to have a very great effect in increasing her leeway. And if we compute the resist­ances for this leeway of six degrees by the actual experi­ments of the French Academy on the angle, we shall find the result not far from the truth ; that is, the direct and lateral resistances will be nearly in the proportion of CI to ID.

It results from this view of the matter, that the leeway is in general much smaller than what the usual theory assigns. We also see, that according to whatever law the resist­ances change by a change of inclination, the leeway remains the same while the trim of the sails is the same. The lee­way depends only on the direction of the impulse of the wind ; and this depends solely on the position of the sails with respect to the keel, whatever may be the direction of the wind. This is a very important observation, and will be frequently referred to in the progress of the present in­vestigation. Note, however, that we are here considering only the action on the sails, and on the same sails. We are not considering the action of the wind on the hull and rig­ging. This may be very considerable ; and it is always in a lee direction, and augments the leeway ; and its influence must be so much the more sensible, as it bears a greater pro­portion to the impulse on the sails. A ship under courses, or close-reefed topsails and courses, must make more leeway than when under all her canvass, trimmed to the same angle. But to introduce this additional cause of deviation here, would render the investigation too complicated to be of any use.

This doctrine will be considerably illustrated by attend­ing to the manner in which a lighter is tracked along a ca­nal, or swings to its

anchor in a stream.

The track-rope is made fast to some staple or bolt E on the deck (fig. 2), and is passed be­tween two of the timber-heads of the bow D, and laid hold of at F on shore. The men or cattle walk along the path FG, the rope keeps extended in the direction DF, and the lighter arranges itself in an oblique position AB, and is thus dragged along in the direction *ab,* parallel to the side of the canal. Or, if the canal has a cur­rent in the opposite direction *ba,* the lighter may be kept steady in its place by the rope DF mode fast to a post at F. In this case, it is always observed, that the lighter swings