The work done in inclining a ship slowly so as to maintain a constant displacement (and avoid communicating any unnecessary movement or disturbance to the water) is given by the expression *^M.dS* where M is the moment resisting the inclination. This may be written

W × *f°GZ.dθ∙,*

and it has been shown above that this is equal to the weight multiplied by the vertical separation of the centres of gravity and buoyancy. This is otherwise evident since the work is the sum of that done against the forces acting on the ship, viz. the weight and the buoyancy; these are respectively equal to W×rise of G, and W×fall of B, giving the value W.(Z'B'-BG) as before.

The *dynamical stability* of a ship at any angle is defined as the work done in inclining the ship from the upright position; and its value is conveniently obtained by integrating the curve of statical stability as stated above. The dynamical stability can thus be calculated at various angles and a curve obtained, whose ordinates represent work done in foot-tons. The curve of dynamical stability is drawn for a battleship (normal condition) in fig. 10, and is there shown in relation to the curve of statical stability; it will be seen that the dynamical stability increases continuously until the righting moment vanishes, when it becomes a maximum.

A formula for the dynamical stability of a ship at any angle was given by Canon Moseley in a paper read before the Royal Society in 1850. Experiments on models made under his direction at Ports- mouth Dockyard showed that the actual work in quickly inclining to a moderate angle agreed closely with that calculated in the case of a model of circular section; but considerable divergence was obtained with a model of triangular section owing to the motion of the water set up, and also, probably, to the variation in displacement during the roll.

The existence of large righting couples at moderate angles of heel is of greater importance in a sailing ship than in a steamship, since in the former it determines the amount of sail that can be safely carried under known weather conditions and thereby influences the speed. A sailing ship in motion is subjected to the wind-pressures on the sails and the upper works of the ship, and to the water-pressures on the hull. When the ship is in steady motion, these forces are equal and opposite; and, so far as the stability is concerned, it is sufficient to determine the trans- verse resultant of the wind-pressure on the sails, and its moment, the water-pressure on the hull affecting only the speed and leeway of the ship.

The pressure on the sails depends on their form and area, their position, and the apparent velocity of the wind, *i.e*. the velocity relative to the ship. The pressure of the wind on the hull is obtainable similarly to that on the sails, but is usually neglected as the heeling moment is small. Experiments have been made to determine the wind-pressure on plates by Dines, Langley, Eiffel, Stanton and others; and the results of the experiments are briefly as follows—

The normal pressure R in pounds on a plate of area A square feet exposed to face normally a wind of velocity V feet per second is given by the formula R = KAV2, where K is a coefficient depending on the form and area of the plate. For a square or circular plate of about I sq. ft. in area K is about .0014, corresponding to a pressure of 1 lb per sq. ft. at about 16 knots. The coefficient increases slightly for larger dimensions of the plate. It has also been found that a departure from the square or circular form involving an increase in perimeter for the same area causes an increase in the mean pressure. An alteration from the plane to the concave, analogous to the “ bellying ” of sails, is accompanied by a slight increase in the pressure per square foot of projected area; but for any large amount of concavity the increase is more than counterbalanced by the decrease in the projected area.

No simple law exists connecting the normal pressure on a plate exposed obliquely to the wind with the angle of incidence; it is found that the results for air exhibit a close agreement with those for water after allowing for the difference of density between the two fluids. At small angles of incidence up to about 20°, or even 40°(varying with the shape of the plate), the pressure varies directly as the angle; beyond this limit it is slightly diminished, afterwards increasing or decreasing to a value which is almost constant for the remaining angles up to and including 90°. The centre of pressure for oblique impact lies between the leading edge and the centre of gravity of the area. In a plate 1 ft. square, it lies 0∙3 ft. from the leading edge at 10° inclination and 0·4 ft. at 30° inclination, gradually approaching the centre of the plate as the angle of inclination is increased. À slight curving or concavity of the plate does not appear to have much influence on the normal component of the wind- pressure.

The wind-pressure on the sails of a ship cannot be calculated with any degree of precision because existing information is insufficient to take account of (*a*) the variety in area and shape of the sails used ; (*b*) the different positions in which the sails may be placed relative to the wind and to each other; and (*c*) the interference of adjacent sails with each other. On the other hand, conclusions based on these experiments are of value both in assisting in an intelligent appreciation of the effects of changes in the sail areas, sail positions, and in the form of rig, and in forming a comparison between the various qualities of speed, stability and general behaviour of vessels with which experience has been obtained.

The stability of a sailing vessel is usually estimated by assuming all plain sail to be placed in a fore and aft direction and to be subject to a normal pressure of 1 lb per sq. ft., corresponding to a wind of about 16 knots. The resultant pressure of the wind is supposed to act through the centre of gravity of the total sail area (termed the *centre of effort).* The resultant pressure of the water on the hull, which is equal and opposite to the wind-pressure, is assumed to pass through the centre of gravity of the area of the immersed middle line plane (termed the *centre of lateral resistance).* If *h* be the vertical distance between these points in feet, A the sail area in square feet, and *α* the angle of heel, the moment causing the heel is (on these assumptions)

7240loot-tons

and the righting moment is approximately

W×GM sin α.

Hence

AÄ

s,n a - 2240ΛV × GM'

The reciprocal of this quantity or

2240. W×GM

AΛ

is a measure of the capability of the ship to stand up under her canvas and is termed the *power to carry sail.* Its value varies with different sizes and classes of ships and boats. It is relatively small in small boats and small yachts owing to the practicability of reducing the angle of heel by movable ballast ; and a low value is also permissible in large yachts on account of their great range of stability. In boats and yachts it varies from 3 to 4 and in full-rigged sailing ships from 15 to 20.

The stability of sailing vessels at large angles of inclination varies considerably with the class of vessel. In racing yachts and other completely decked sailing boats whose ratios of beam to depth and draught are comparatively small, initial stability is obtained by lowering the centre of gravity with ballast fitted on the keel, and the range then extends to considerably over 90°; on the other hand, a number of half-decked or open sailing boats immerse their gunwales when inclined to a moderate angle. With reference to this, Mr Dixon Kemp in his *Yacht Architecture* remarks that the deck edge should not be immersed at an angle of heel less than 20°; some small centre-board boats whose gunwales are awash at 12° or 15° cause anxiety. With full-rigged sailing ships this angle is commonly 20° to 2Γ∙

The effect of a sudden gust *of* wind on a sailing ship is obtained by equating the work done on the ship by the gust to her dynamical stability; and the angle at which this equality holds will be the extreme angle of heel, assuming the ship to be originally upright and at rest. Since the dynamical stability is represented by the area of the statical stability curve it is convenient to represent this angle in relation to this latter curve. The effects of the resistance and inertia of the water and any change of displacement are neglected; the wind-pressure is assumed constant during the roll, in accordance with the results of experiments on oblique plates (the maximum angle of roll being supposed less than 50°; the modification of the pressure due to the motion of the sail is also neglected.

Let OPQ (fig. 20) be the curve of statical stability, the ordinates representing righting moments, and let the heeling couple due to the gust be represented by OS. If N be the extreme angle of heel, draw SPUR parallel to the base, cutting the curve at P, R; and PM, NQ perpendicular. The work done by the wind is the area OSUN and is equal to the dynamical stability of the ship or the area OPQN. Hence the areas OPS, PQU are equal, and the extreme angle of heel is deter- mined by this equality. If P and Q lie on the initial and approximately straight portion of the curve, the extreme angle of heel ON is about twice that of the steady angle OM corresponding to the strength of the gust. The area QUR represents the reserve dynamical stability when the wind is blowing with strength corresponding to OS; the intercepts of the ordinates below SPUR doing work against the force of the wind, leaving the segments above SPR available for absorbing the kinetic energy possessed by the vessel at the position of steady heel PM. As the strength of the gust is increased the points P and Q travel farther along the curve until P', *Q,* are reached, such that the areas P'Q'Q, OTP' are equal; the vessel will then come momentarily to rest at Q' and will be in unstable equilibrium, any increase in the wind-pressure causing her to capsize. It follows that a ship sailing in a wind of sufficient strength to cause a moderate angle of heel equal to OM' will be on the point of capsizing if the wind should happen to drop and afterwards return suddenly with its