The Flettner Rudder

Clearly Explained by a Working Meccano Model

By H. F. Lane

In last month's "M.M." Mr. Lane explained the underlying principles of the Flettner Rudder, and referred to the installation of the actual gear in vessels of various types. Below he describes a remarkable Meccano model that demonstrates the action of the Flettner Rudder in a clear and extremely interesting manner. With the exception of a length of brass tubing, which may be obtained for a few pence from most metal merchants, the model is constructed entirely from standard Meccano parts.

BEFORE commencing to describe the Meccano model it will be necessary to study the manner in which the operating cams on the rudder head actuate the secondary rudder. This should be clear on reference to the diagrams shown in Figs. 1 to 4. In order to make the drawings easier to follow, one of the cams and its corresponding roller have been shaded in each drawing. The roller 6 on one end of the rocker arm 4 runs round the periphery of the cam 1, and the roller 7 runs on the cam 2.

It will be remembered from last month's description of the rudder mechanism that the quartermaster's wheel is connected to the cams 1 and 2, which turn about a pivot as a single unit, and the rocker arm 4 is connected to the secondary rudder. In Figs. 1 and 2 the quartermaster's wheel, and therefore the cams 1 and 2, are in the "midships" position. In Fig. 1 main and secondary rudder
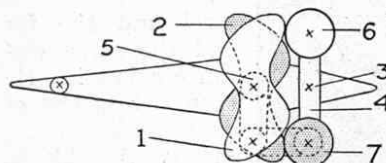

Fig. 1

are in the normal position and the vessel moves straight ahead.

In Fig. 2 the main rudder has been deflected 30 degrees by external forces, and consequently the rocker pivot 3 has been carried round this amount relative to the cams 1 and 2. Owing to the design of the cams, this movement has the effect of angling the rocker arm 30 degrees relative to the main rudder, and the movement of the rocker arm, transmitted by links and cranks to the operating shaft 5 that passes down through the hollow rudder stock, angles the secondary rudder 30 degrees relative to the main rudder, or 60 degrees relative to the fore and aft line of the ship, thereby producing an increased unbalanced pressure tending to return the main rudder to the midships position. As the main returns, the angle between rocker and main reverts to its original setting, so that, as the main reaches the midships position the system is once more in equilibrium.

The cams are so designed that a critical point occurs in the angling every 45 degrees. Since the relative angle between the secondary and main is a direct function of the relative angle between the centre line of the cams and the main, a deflection of the main of 45 degrees will cause the mean position of the secondary to be deflected 45 degrees relative to the fore and aft lines of the ship, and a further deflection of the secondary of 45 degrees relative to its mean position. Thus the total deflection of the secondary rudder is 90 degrees relative to the fore and aft lines of the ship.

In other words, the secondary is now at right-angles to the direction of the stream, and exerts a maximum effect trying to return the main.

By studying Fig. 2 it will be seen that if the main rudder is deflected more than 45 degrees the rollers pass their critical

Fig. 3

points on the cams, and therefore the angle of the rocking arm relative to the main is diminished. Consequently the secondary's angle relative to the main is reduced by an amount equal to the angle of deflection of the main, relative to the ship, in excess of 45 degrees. Thus the secondary is maintained at right-angles to the stream and continues to exert a maximum turning moment.

The above deflections are far larger than could occur in practice. They have been discussed in order to demonstrate the principles more clearly.

The fulfilment of the conditions laid down in paragraph (c) (2) in last month's "M.M." is carried out in the following manner. Suppose that the engines are put astern while the rudder is normal, as in Fig. 1. Though the ship will still carry her headway for

some minutes, the powerful sucking effect of the propeller will reverse the direction of the stream in the vicinity of the rudder. Since it is this stream that steers the ship, the rudder must adjust itself at once to the new conditions without waiting until the ship herself has gathered stern way.

Theoretically, if the whole system were in stable equilibrium beforehand, the main rudder would remain in the original position under these new conditions, but in unstable equilibrium. In practice this position could not be maintained more than a few seconds, but to enable the rudder to take up its new position still more quickly, the quartermaster is instructed that whenever the engines are reversed—either from "ahead" to "astern" or vice versa—he is immediately, without further orders, to put full helm (whether starboard or port is immaterial) on the secondary rudder, thereby producing the unbalanced pressure needed to give the main its initial start from its position of unstable equilibrium. Once started, the main continues to swing round, and as soon as the main indicator records 45 degrees, or even before, the quartermaster centres the secondary and leaves the cams to maintain automatically the secondary rudder normal to the stream exerting the maximum precessing couple.

Fig. 2

So far we have considered the ship only on a straight course, which the quartermaster maintains by small helm angles, sometimes to port, sometimes to starboard, as in ordinary power-operated steering gear. In order that a ship may answer her helm effectively under any circumstances, the conditions laid down in paragraphs (a) and (b) (1) must be fulfilled satisfactorily.

Suppose, for example, that the officer of the watch has ordered "starboard 30." The quartermaster spins his wheel the requisite amount, thereby angling the cams 1 and 2 30 degrees in a clockwise direction (see Fig. 3). This causes the rocker 4 to move through a similar amount, causing the secondary rudder to angle 30 degrees in an anti-clockwise direction relative to the main. The resultant reaction of the stream of water impingeing on the angled secondary causes the main rudder to precess in a clockwise direction, thus turning the ship to port. But as the main rudder turns it carries with it the rocker pivot 3. This makes the rocker rollers 5 and 6 "hunt" their original positions on the periphery of the cams, thereby diminishing the angle of the secondary until a position of equilibrium is finally found wherein the small amount of deflection remaining is just sufficient to meet the unbalanced pressure acting on the main due to its deflection.

This is indicated in Fig.

Fig. 4

4 where the cams have been angled 30 degrees and the main has precessed 20 degrees, leaving 10 degrees on the secondary to hold it in the position at which equilibrium is assumed to occur. It should be noted that the cam—or control—indicator on the bridge is calibrated to allow for this. Thus, assuming the above ratios to be correct and the officer of the watch to have ordered starboard 20 degrees the quartermaster would spin his wheel until starboard 20 shows on the cam indicator, though to affect this he would actually angle the cams 30 degrees. As a result, with the ship turning in calm water and no wind, starboard 20 should appear on the main indicator, but even if the main indicator swings to 25, drops to 15, and finally settles at, say, 22 the quartermaster disregards it, secure in the knowledge that the sensitive control
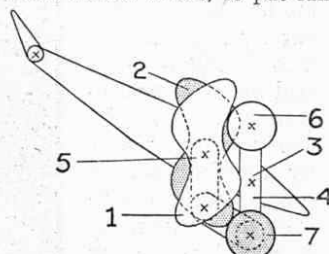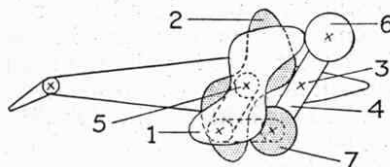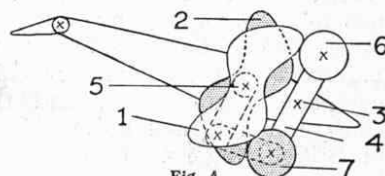
is creating a consistent starboard 20 effect throughout.

The effort of the main to keep in step with the cams is no less sensitive when they are angled than when they are amidships. Considering Fig. 3 as a deflection of the main rudder by external forces from the position shown in Fig. 4, the motion of the rocker pivot relative to the cams has increased the secondary angle, and created the precessing couple. A similar but opposite effect occurs when the main suffers deflection in the reverse direction.

The actual rudder proportions determined from a long series of experiments are : area of secondary to area of main rudder, 1 : 8 ; area of main before stock to area of main abaft stock, 1 : 2.35 ; and greatest breadth of main (at stock) 1 : 6.6 of its length. These proportions are reproduced very closely in the Meccano model.

The secondary exerts, of course, a small turning moment in the direction opposite to that in which the main rudder is operating. This actually works out at about 2/13th of the whole moment exerted by the main rudder, leaving 11/13th to steer the ship, and therefore is inappreciable.

Construction of the Model

The construction of the model should be commenced by making the main rudder. Both sides of the rudder are similar and are composed of two 5½″×3½″ Flat Plates 1, a 5½″×2½″ Flat Plate 2, and a 2½″×2½″ Flat Plate 3 (Fig. 6). The latter overlaps the upper 5½″×3½″ Flat Plate by two holes. The leading edges of the Plates 1 and 2 are carefully bent so as to preserve the steam-line section, as also are the projecting portions of the 2½″×2½″ Plates 3.

The two halves of the rudder are spaced apart at top and bottom by Flat Girders, a 3½″ Flat Girder being used for the top, and a 4½″ Flat Girder for the bottom. Both Flat Girders are secured to the Plates by ½″×½″ Angle Brackets.

The secondary rudder, or Flettner "fin," is composed of two pairs of 2½″ Flat Girders 4, which are bolted at their trailing edges one on each side of a 5½″ Strip that gives rigidity to the whole. The leading edges of the Flat Girders are prised apart and pushed on to four Couplings arranged on

Fig. 5. General view of the Meccano Model

an 8″ Rod 5. Ordinary bolts are used to secure the Flat Girders to the Couplings, one Washer being placed on each bolt between the Couplings and Girders. The top end of the Rod 5 is journalled in the Coupling 5a and the lower end in a 1″ Triangular Plate bolted to the 4½″ Flat Girder forming the bottom of the rudder.

The stock 6 consists of a 7½″ length of ⅜″ inside diameter brass tubing, which can be obtained for a few pence from most metal merchants. It is drilled at certain points to enable it to be attached to the Couplings 7 and 8.

A bolt is passed completely through a hole in the stock 6 and then inserted in a diametrically opposed hole so that its shank projects outside the stock 6. The bolt is then screwed home in the threaded bore of the Coupling 7, a nut being placed on the shank of the bolt and locked against the tube to prevent the bolt working loose. The Octagonal Coupling 8 is also secured to the stock by a bolt.

The control shaft consists of an 11½″ Rod 9, which passes down through the centre of the stock 6, and is journalled near its bottom end in the Octagonal Coupling 8. The motion of the Rod 9 is transmitted to the secondary rudder via the ⅞″ Bevels 10 and the ¾″ Contrate Wheel and ½″ Pinion 11. The 3″ Rod carrying one of the ⅞″ Bevels and the ½″ Pinion is journalled in Couplings that are fixed to the side Plates 2 by ⅜″ Bolts. It is necessary to place one Washer on each of the ⅜″ Bolts between the Couplings and the side Plates in order to obtain the correct spacing.

The method of fixing these two Couplings applies also to the Coupling 7. The Octagonal Coupling 8 is secured between the Plates 2 by ½″ Bolts passed through the Plates and inserted in the sides of the Coupling. Five Washers should be placed on each bolt to space the Coupling centrally in the rudder.

When the two halves of the rudder are fitted together, the leading edges of the Plates 1 and 2 and the trailing edges of the 2½″×2½″ Flat Plates 3 are drawn together by means of the ⅜″ Bolts. This gives a correct streamline section to the main rudder.

The roller bearing 12 consists essentially of four ½″ fast Pulleys mounted loosely on ¾″ Bolts. Each of these bolts is inserted in one of the four centre holes of a Wheel Flange. A second Wheel Flange, which forms the top cover of the bearing, is secured in place by nuts on the ends of the bolts (see Fig. 5). The ½″ Pulleys bear on the rudder stock and so maintain it in the correct vertical position. The complete roller bearing unit is fixed to the horizontal 12½″ Angle Girders of the frame by two of the ¾″ Bolts carrying the ½″ Pulleys.

In order to eliminate the specially shaped cam plates that would be necessary with an orthodox model of the Flettner rudder, a very simple device is employed. It is in the form of a double sun-and-planet gear contained in the operating head.

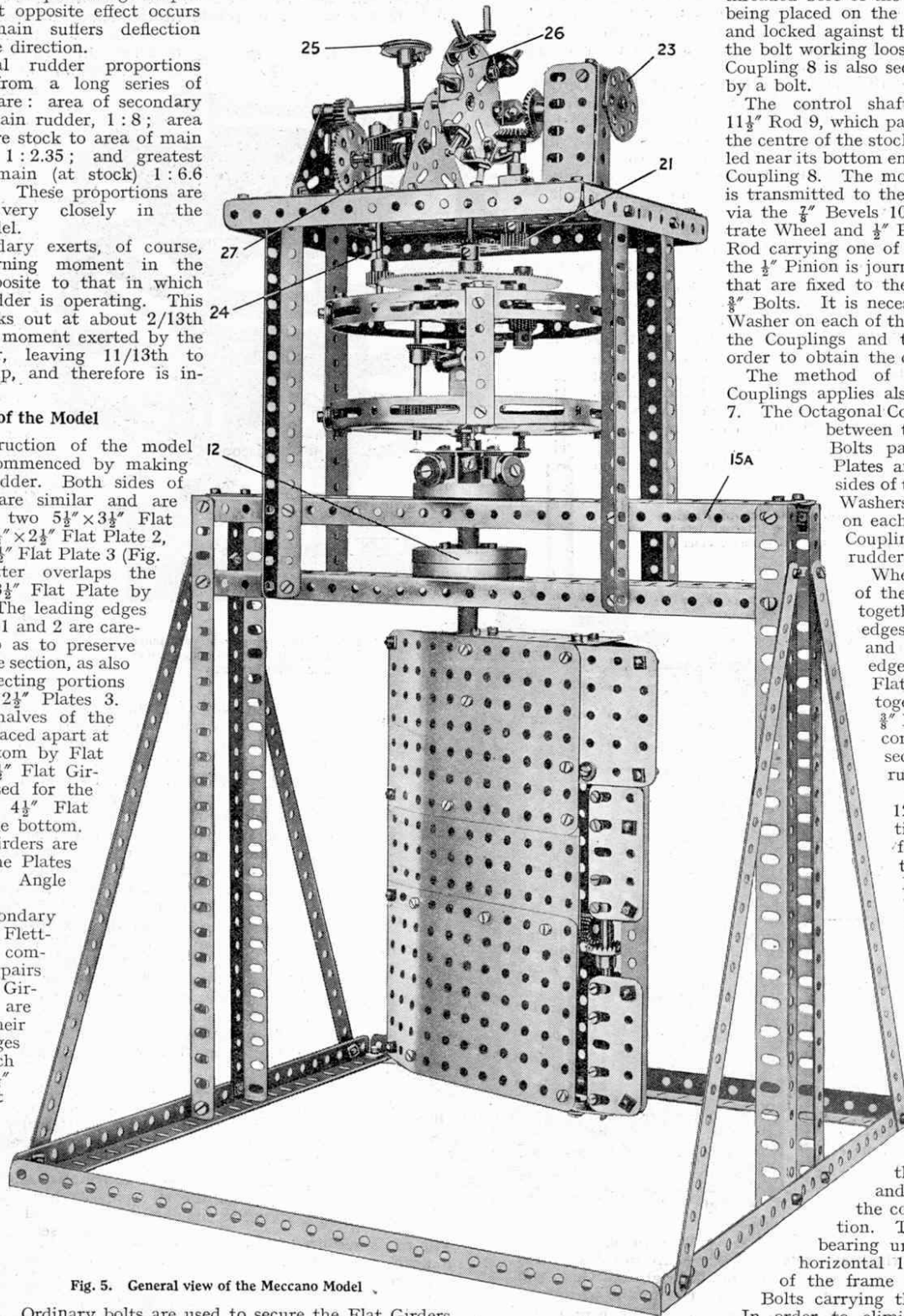The operating head (see Fig. 7) consists of two Hub Discs spaced

apart by a number of 2½″ × ½″ Double Angle Strips, and is secured rigidly by a number of ½″ bolts, in the manner shown, to a Face Plate 13 that forms the upper half of the top roller bearing unit. Each ¾″ loose Pulley forming a roller of the bearing is journalled on a ⅜″ Bolt that is held in a Threaded Boss 14. In order that the ¾″ Pulleys shall not come into contact with the underside of the Face Plate 13, the Threaded Bosses 14 are packed away from the latter by two Washers on each of their retaining bolts. The ¾″ Pulleys normally ride on the edge of the Wheel Flange 15, but they are shown raised free of this guide so that their arrangement may be seen more clearly.

The Wheel Flange 15 is bolted to the two 12½″ Angle Girders 15a of the demonstration frame (Fig. 5). Thus the two roller bearing units 12 and 15 serve to retain the rudder in the best possible manner, the bearing 12 taking up the side play and the bearing 15 taking the direct weight of the rudder.

The top of the rudder stock 6 is secured rigidly to the boss of the Face Plate 13 (see Figs. 5 and 7) by an ordinary bolt, which is passed through a hole in the stock and screwed into the set-screw hole of the Face Plate. A nut is used to prevent the bolt touching the control shaft 9, which must revolve freely within the boss of the Face Plate. It will now be realised that the whole of the operating head rotates as one with the main rudder, and that the control shaft is quite free to turn independently of the stock and operating head.

The 50-teeth Gear Wheel 16 is secured to the top of the control shaft 9, and meshes with a ¾″ Pinion fixed to a 3″ Rod that is journalled in holes in the top and bottom Hub Discs. On the same Rod is a Crank 17, which has its arm prolonged to two inches between centres by a 2″ Strip bolted to it. The 3″ Rod 18 has a 57-teeth Gear Wheel 19 secured to its lower end.

The Gear 19 is in mesh with the ½″ Pinion mounted on a short Rod that is journalled in the upper Hub Disc and in one of the holes of the 3″ Gear Wheel 20. A Crank 21 is attached to this Rod and is connected to the Crank 17 by means of a 2″ Rod that is mounted pivotally on the Cranks by means of Collars, ordinary bolts being passed through the end holes of the Cranks 17 and 21 and inserted in the set-screw holes of the Collars. It will be observed that the Crank 21 is equipped with a Flat Bracket, the round hole of which coincides with the elongated hole of the Crank and forms a bearing for the bolt secured to the connecting rod.

A 57-teeth Gear secured to the upper end of the Rod 18 is in mesh with a ½″ Pinion 21 (Fig. 5), which is mounted on a short Rod carried in a foot-step bearing consisting of a Double Bent Strip bolted to one of the 5½″ × 2½″ Flat Plates that represent the "deck." As will be seen, the short Rod carries at its upper extremity a ⅞″ Bevel that meshes with a second Bevel actuated by the steering wheel 23. To ensure that the 57-teeth Gear and the Pinion 21 (Fig. 5) engage correctly, it is advisable to journal the top end of the Rod 18 in one of the holes of the Flat Plates comprising the "deck." The 3½″ Gear 20 is attached to the upper Hub Disc by ½″ Bolts in a similar way to the Face Plate 13.

Rotation of the Bush Wheel 23 causes the Gear 19 (Fig. 7) to be operated via the ⅞″ Bevels and the ½″ Pinion 21 (Fig. 5) meshing with the 57-teeth Gear on the Rod 18. Thus the Crank

Fig. 6. Section of Rudder showing internal details and secondary rudder

21 (Fig. 7) is caused to rotate, and with it the second Crank 17, which operates the control shaft 9 through the medium of the 50-teeth Gear 16.

As a result of the angle thus set on the secondary rudder, the main precesses to a new position, but in so doing carries round with it the two vertical shafts mounted in the Hub Discs. Since the 57-teeth Gear 19 is at rest, this motion causes the ½″ Pinion that meshes with it to rotate in the opposite direction to that in which it was turned originally, thereby diminishing the angle of the secondary until equilibrium is found.

Similarly, if external deflection takes place on the main after the latter has been placed in any position the secondary rudder automatically alters its angle, because the Pinion actuating the Crank 21 (Fig. 7) travels round the stationary Gear Wheel 19. The turning moment exerted by the secondary then restores the main to whatever angle of helm had been set previously. When the main rudder arrives at its former position it will be found that the secondary rudder is also in its original position.

Fig. 7. Operating head of Rudder, showing control mechanism and roller bearings

It is necessary for the Crank 21, which has to turn complete circles, to be shorter than the Crank 17, in order that the latter shall never be at a dead point. At the same time, the control shaft and operating shaft 18 must turn through equal angles. The arrangement given here provides for these angles being equal with sufficient accuracy up to 30 degrees or 40 degrees on either side of the mean position—i.e., for controlling the main rudder when on a steady course, or for setting the maximum helm angle that can be applied by the quartermaster.

To render the rudder controllable by the emergency hand steering gear (Fig. 5) the 1″ fast Pulley 25 on the end of the 3½″ Threaded Rod is rotated until the ½″ Pinion on the end of the 3½″ Rod 24 is brought into engagement with the 3½″ Gear Wheel 20.

The ½″ Pinion near the upper end of the Rod 25 is brought simultaneously into mesh with the Worm 27, so that when the hand steering wheel 26 is turned, the Gear 20 is moved and with it the main rudder.

As stated in last month's article, the Board of Trade regulations provide that a ship must be capable of control by hand in the event of the mechanical gear failing. The subject of emergency hand steering gear was dealt with more fully in another article (see "M.M." for November, 1926), and a Meccano demonstration model of a typical arrangement for steering a ship by hand was described in detail in that article.

The parts required to build the Meccano Model are as follows :—

4 of No. 1	1 of No. 14	1 of No. 27	5 of No. 48A	1 of No. 77
1 " " 2	3 " " 16	3 " " 27A	4 " " 52A	1 " " 80A
1 " " 6	3 " " 16B	1 " " 27B	10 " " 59	1 " " 103C
2 " " 6A	4 " " 17	1 " " 29	2 " " 62	1 " " 103D
12 " " 8	1 " " 18A	4 " " 30	1 " " 62A	6 " " 103F
4 " " 8A	1 " " 22	8 " " 32	8 " " 63	4 " " 111
2 " " 8B	4 " " 23	112 " " 37	1 " " 63A	8 " " 111A
2 " " 9	4 " " 23A	20 " " 37A	1 " " 64	28 " " 111C
1 " " 10	2 " " 24	50 " " 38	5 " " 70	8 " " 115
2 " " 11	1 " " 25	2 " " 45	2 " " 72	2 " " 118
18 " " 12	6 " " 26	1 " " 46	2 " " 76	3 " " 137
1 " " 13				

1 brass tube as specified