CHAPTER XIII.

HOW TO MAKE A SHIP HANDY AND EASY TO STEER.

Handiness.

ONE part of handiness consists of balance of sail; a second, a balance of ship; and a third, of proportion of rudder.

Balance of sail.

First, of balance of sail.

Unless sail be balanced, the ship will go just where it pleases, or just wbere the wind pleases, instead of where the pilot chooses. If there be a sail on the fore-part of the vessel only, the wind will blow the fore-part of the vessel to leeward, and she will drive head foremost. If there be a sail on the after-part of the vessel only, the wind will blow the after-part to leeward, and she will drive stern foremost before, or head to, tbe wind. In order that neither of these should happen, the sail on the fore-part must be so placed and proportioned to the quantity and place of the sail on the after-part, that they exactly balance one another in effect, so that neither one nor the other can prevail. This is virtually to take away from the wind all power of determining tbe direction of the ship, and a good sailing-master, by properly regulating this balance of sail, can keep the direction of the ship's head exactly which way he pleases.

Balance of ship.

This is balance of sail, but it depends on another element, namely, balance of ship. These must exactly suit each other, otherwise there will be no balance. I will suppose the effect of the sail at the bow to be exactly balanced by that at the stern; but, nevertheless, there will be no enduring balance if the bow be more easily forced to leeward than the stern, for then the head of the ship would go round to leeward. The effects of the fore-sails and the after-sails being balanced between themselves, and the effect of the fore-part and of the after-part of the section of the ship lengthways in the water balanced between themselves, the one called "trim of sail," the other "trim of ship;" the naval architect must provide by forethought for the due balance of both, and afterwards the painstaking thoughtfulness of the sailor must maintain in all circumstances this equilibrium.

Must each be adapted to the other.

It is thns only that we can get and keep a handy ship. The sails must balance; the body must balance: both must be kept together in perfect trim. The hand of the pilot and the blade of the rudder must do the rest.

Something more required for quickness.

Something more, however, can still be done by the uaval architect to give the master complete command over the ship. The balance he has established is enough to deprive the wind of the control of the vessel, and give it to the master, bnt the ship may still require from him the exertion of very great controlling force when he wishes, iu the course of his manœuvres, to change the ship's head round rapidly from one course to another. Balance of sail and of body will help him to do this, but will not help him to do it quickly.

To make a vessel very handy, and pivot about very quickly, sail, can keep the direction of the ship's head exactly which way he pleases.

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namely, that lateral resistance should be chiefly in the middle, and not at the ends.

To make a vessel very handy, and pivot about very quickly, her longitudinal section should be deep, rather than long, and when its extreme length is decided, its effective length should be diminished as much as possible by removing longitudinal area from the ends, and placing it near the middle. Above all, much cut-water and fore-foot make a vessel unhandy and slow to come round. It is better, therefore, to have dead wood aft than forward, but removed from both ends as much as possible: rounding off the fore-foot and shortening the heel, are the most effectual ways to make a ship handy without injuring her other qualities; the effect of heel and fore-foot being to cause gripe, or resistance to turning round, which is the contrary of handiness.

With balanced ship and balanced sail, good trim, and little gripe, not much can be wanting to handiness. The rudder must do the rest. In these circumstances the rudder is nothing more than a means to hinder one side of the ship from getting forward so quickly and easily as the other, and so giving a bias to one side. The side which the rudder hinders falls behind, while the other gains an advantage over it, and turns round it. "Helm hard-a-lee," makes the ship go round to leeward. "Helm hard-a-port," makes her go round to port: beyond this, there is nothing in a rudder. It is a power to hinder—it puts a drag on one side, it always diminishes speed, it never helps anything, and the cleverest helmsman is he who uses it least, the best ship is that which wants it least, and the best sailor is he who does most without it. A steersman, always yawing his ship about, steers badly; a ship taking much helm is badly trimmed; sails requiring much rudder are badly set. Nevertheless, it is above all things necessary that the rudder have ample power—great power, seldom used. A ship that will go for hours and hours with scarcely a touch of the helm is a ship well sailed; but, when wanted, the rudder must be able to do anything; and to be able to make a ship turn short and sharp round on her heel, may save her. The way to give power to a rudder seems to be no secret: it must bear a certain proportion to a ship's length. A long ship requires a broad rudder. I consider that for every 100 feet in the length of a ship, she wants 2 feet breadth of rudder, and 1 more; thus—100 feet long, will have a 3-feet rudder; 200 feet long, a 5-feet rudder; and 700 feet long, a 15-feet rudder.

Effect of rudder.

Rudder should be powerful, but sparingly used.

Proportion of rudder to ship's length.

As to shape of rudder, there is little or nothing in it. Half the world say the top of the rudder is the most valuable part, where the water has most effect, and that the rudder should be widest there. The other half say it should have most bottom, for that bottom is most effective. I think both are crotchets; but there may be something peculiar in the case of some ships, to render both exceptionally true.

Shape of rudder not very material,

The fault of having the widest part of the rudder above is, that there exactly a rough sea will strike the rudder most heavily; so that in heavy weather, when you want the helmsman to have most command of his helm, you enable the sea to strike it out of his hand. This is a grave error.

Of the two, there is less harm in making the rudder widest near the heel, for, being well buried under water, the wave surface of the sea has less action upon it, and so in bad weather the helmsman is able to command his ship as he ought. But, on the other hand, the heel of the ship, especially in the old wooden screw-ships, may be her weakest part, and to put more strain than necessary on a weak place is scarcely wise. The result is, that if a rudder must have a widest place, it is better that it should neither be at the top nor at the bottom. It is wise, perhaps, to round off the rudder gently both towards the heel and the head, so that the rounding of the heel shall keep it out of the way of striking the ground in a shallow or narrow channel, and the rounding above shall keep it from being struck heavily by surface waves.

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There will always be a delicate question about the quantity of rudder to be given to a vessel destined for any special purpose. If you believe that your rudder will always be committed to wise hands, who will never use more than enough, you may safely give them plenty of rudder, leaving it to their discretion to spare its use. Strictly speaking, such people should have as much rudder as they can conveniently command and handle, because with powerful rudders you can make a ship perform manœuvres impossible with small ones. To be able to come round very fast will often give a ship the weather-gauge of another, and in the contest of war for victory, or of sport for a challenge cup, ability to execute difficult manœuvres rapidly is often in itself a source of success. A ship well in hand is often better than one which is faster, but runs wild. Therefore, put into the hands of a wise man a powerful rudder.

Caution as to giving too much rudder-power, except to a discreet commander.

Unluckily, the naval constructor has sometimes the misfortune to have his finest tools intrusted to the hands of fools. In such cases it is to be desired that the rudder should be proportioned to the capacities of the man, and not to those of the ship, and then the rudder should not be so powerful as to enable the ship rapidly to perform the intended manœuvre, lest it should outrun the wits of the fool in command. The ship should be able to come round only just so quickly that the governing intelligence may keep pace with her movement, and see what she is going to do. Only, therefore, to a quick-witted man intrust a quick-working ship.

For a slow ship, and a slow captain, a rather narrow rudder will be the best. The motions of the ship will, in that case, be slow; they will give time for thought, and will be less likely to run the vessel into mischief. For such ships two-thirds of the dimensions I have given will be enough.

Of the exact proportions of ship's body, of sail area, and of rudder surface, which go to make a ship all we may desire, more will have to be said in detail under the three separate heads.

CHAPTER XIV.

ON BALANCE OF BODY AND BALANCE OF SAIL.

Handiness depends on balance of sail.

WE have seen that handiness, manageableness, or ready obedience of a ship to the will of her commander, arise out of the due combination of balance of sail, balance of body, and power of rudder; we have seen how, without these, a vessel steers wild, and flies beyond control; that with too much fore-sail the vessel drives to leeward head foremost, and with too much after-sail she drives to leeward stern foremost, or, which is the same thing, her head comes up into the wind. In the same manner, if the body be unbalanced, having too much gripe, or hold of the water forward, the stern will drift down to leeward; and if too little hold of the water forward, the bow will fall off to leeward.

Ardency and leewardliness.

When, either through want of balance of sail, or of balance of body in the water, the ship shows a tendency to fall off at the bow to leeward, or to fall off at the stern to leeward, she is said to have two opposite defects —one called leewardliness,* and the other called ardency. These defects ought to be corrected, either by trim of sail or by trim of ship. If not corrected, they must be counteracted by the action of the rudder; but, as the rudder is a hindrance applied on one side, and in no case a help, speed is lost in the degree in which the rudder is used. The tendency to go up into the wind, and the tendency to fall off the wind, or ardency and its opposite, require palliatives of opposite kind. Ardency implies that the ship must always carry weather-helm; want of ardency implies that she must always carry lee-helm. Of these two evils ardency is reckoned the less; aud it is therefore usual to trim a ship so that she shall always carry a *very* little weather-helm.

Centre of effort of sail should correspond with centre of lateral resistance.

The point in the length of the ship, on both sides of which the sails halauce, is called "the centre of effort of the sails;" the point in the water on both sides of which, fore and aft, the body balances—or, to put it otherwise, the point in the air on both sides of which, fore and aft, the pressure of the wind on the sails balances, and the point in the water on both sides of whicb, fore and aft, the resistance of the water to the leewardliness of the ship balances—these are respectively called "the centre of effort of sail," and "the centre of lateral resistance of ship."

In a state of perfect trim of sail and trim of ship, that is, wheu a ship is so perfectly balanced as to be neither ardent nor leeward, reqniring neither lee nor weather-helm, the centre of effort and the centre of resistance would meet exactly in the same point of the length of the ship, and so the effort of sail and resistance of water fore and aft exactly connterpoise one anotber. Unfortunately, there are few ships so constructed as that

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this happy coincidence shall take place and be maintained at all speeds, and in all states of wind and weather. In a perfectly mathematically formed "wave-line" vessel the coincidence of the two has been found to be exact the rudder is a hindrance applied on one side, and in no case a help, speed is lost in the degree in which the rudder is used. The tendency to go up into the wind, and the tendency to fall off the wind, or ardency and its opposite, require palliatives of opposite kind. Ardency implies that the ship must always carry weather-helm; want of ardency implies that she must always carry lee-helm. Of these two evils ardency is reckoned the less; and it is therefore usual to trim a ship so that she shall always carry a *very* little weather-helm.

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Exact coincidence only obtained in wave form.

In a state of perfect trim of sail and trim of ship, that is, when a ship is so perfectly balanced as to be neither ardent nor leeward, requiring neither lee nor weather-helm, the centre of effort and the centre of resistance would meet exactly in the same point of the length of the ship, and so the effort of sail and resistance of water fore and aft exactly counterpoise one another. Unfortunately, there are few ships so constructed as that this happy coincidence shall take place and be maintained at all speeds, and in all states of wind and weather. In a perfectly mathematically formed "wave-line" vessel the coincidence of the two has been found to be exact and perfect; but, with the slightest deviation from the wave form, the perfection of this balance is at once deranged. In order to correct this want of adjustment, the centre of effort of the sails has to be moved forward; and in such a vessel as the "Duke of Wellington," for example, the whole of the masts and sails had to be placed forward from the true centre of resistance as much as 14 feet. In every vessel built on the old

* Leewardliness is used in two senses, both of them equally sanctioned by a common usage, so well established as to be past remedy. It is used, as in Chapter XII., to express facility of drifting to leeward, and as in this chapter, for a tendency to fall off the wind. A little attention on the part of the reader will prevent his being confused by the ambiguity.

system, this derangement of balance had to be taken into account, and allowed for, as an element in the original construction of the ship. Unluckily, it had to be allowed for by guess merely; and, therefore, nothing was so common as to hear that a new vessel had to undergo an entire change of arrangements from the impossibility of managing her, owing to the centres of effort and lateral resistance not coinciding. In such a case the usual remedy (if the error was slight) was to rake the masts a little forward or a little aft, in order to correct the balance of sail, or to put on a little dead wood forward or abaft, or to add a tapering false keel—all for the purpose of restoring the lost balance; and when these expedients failed, the masts, or some of them, had to be entirely moved out of place; an arrangement not only costly, but deranging to a great extent the interior economy of a ship of war.

Remedies in vessels of other shape.

It must be reckoned a fortunate element in the system of wave-line construction that the derangement between the centre of effort of sail and centre of resistance of body vanishes. It is impossible to adjust these two centres to a more perfect balance for practical use, so as to have a ship easy to steer, requiring little helm, quite under command, and handy, than by merely taking care that they coincide in the same point of length.

But it is equally necessary to observe that this perfection of balance and handiness is not to be obtained without an equal perfection of wave form. Every such deviation from exact truth in the form of a ship will exhibit derangement of balance. In exact proportion as any part of the bow is filled up beyond the pure wave line, the balance of sail and resistance will be disturbed, and it will be necessary, either to correct the shape of body, or to remove the centre of effort of sail forward, or to shift the centre of lateral resistance aft. The reason of this seems to be sufficiently plain. The wave form is the form of least resistance: its truth of construction is practically shown when the vessel (in deep water) shows no bow-wave, or breaks no water at the bow. Any untruth in the wave form at once shows itself in broken water, or the well-known wave on the bow, which is bad. The appearance of this obstacle to progress shows exactly where there is an expenditure of undue force, and it is this undue force and unnecessary resistance which deranges the centre of lateral resistance of the ship, and shifts it forward. Its tendency to do so increases with the velocity of the ship. It is to meet this shift of pressure, and to counteract it, that the centre of effort of the sails must follow it forward. But no one can tell precisely beforehand how much any deviation from truth in the form of the ship will remove the centre of resistance, and, therefore, it is impossible to say, what change in the centre of effort may be required to correct it. Unluckily, also, the deviation arising from incorrect form varies with the speed, so that the difference which will restore the balance is not the same for all speeds.

Departure from wave form moves centre of effort of sail forward;

and their deviation varies with speed.

No certainty, therefore, is to be obtained on this point, except by the preservation of the absolute truth shape of body, or to remove the centre of effort of sail forward, or to shift the centre of lateral resistance aft. The reason of this seems to be sufficiently plain. The wave form is the form of least resistance: its truth of construction is practically shown when the vessel (in deep water) shows no bow-wave, or breaks no water at the bow. Any untruth in the wave form at once shows itself in broken water, or the well-known wave on the bow, which is bad. The appearance of this obstacle to progress shows exactly where there is an expenditure of undue force, and it is this undue force and unnecessary resistance which deranges the centre of lateral resistance of the ship, and shifts it forward. Its tendency to do so increases with the velocity of the ship. It is to meet this shift of pressure, and to counteract it, that the centre of effort of the sails must follow it forward. But no one can tell precisely beforehand how much any deviation from truth in the form of the ship will remove the centre of resistance, and, therefore, it is impossible to say, what change in the centre of effort may be required to correct it. Unluckily, also, the deviation arising from incorrect form varies with the speed, so that the difference which will restore the balance is not the same for all speeds.

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No certainty, therefore, is to be obtained on this point, except by the preservation of the absolute truth of the wave form.

Straight middle body gives ardency.

There is another curious cause of deviation between the centres of effort and resistance. If a ship has a long, straight, middle body, she will have a tendency to ardency, arising from length alone. Even if the two ends be perfect wave-ends, a long, straight, middle body will have this tendency to disturb their balance. Of this singular phenomenon of deviation, arising from length of middle body, I will not pretend to give an exact measure, but I will attempt an explanation of a fact which it is impossible to ignore. A long, parallel-bodied ship certainly loses her power to carry after-sail; and if I must venture an explanation, it is, that a long ship, by the mere progress of its skin through the water, drags with it, and puts into motion by adhesion merely, so great a quantity of the water in its neighbourhood, that at the last, when near the stern, the water has ceased to offer lateral resistance, because it has already received the same motion as the ship herself. At the stern, therefore, there is little or nothing left to resist the ship; and so, from deficiency of stern resistance, the after-part loses power to carry after-sail, and the ship becomes ardent. Even wave-formed ends, therefore, will not compensate for this fault of long middle body. If I am asked to what limit this extends, I may say that in a vessel 60 feet beam, with 90 feet of middle body, it has not been sensible, but with similar ends with 100 feet middle body, it has become a very sensible quantity. This deviation, therefore, from the true form, while it is attended with mercantile advantages not to be despised, must be taken with its disadvantages. In order thoroughly to apprehend the nature of this fact, let us conceive a thin, flat board, moving edgeways through the water, and also pressed sideways by a force like the wind at right angles to it. Let us next consider what happens to a particle of water placed to leeward of this thin board. When the board first touches it, it has no leeward motion, but it immediately acquires it;—small at first, but gradually growing, as the following parts

Explanation.

of the board successively press it, and, as each succeeding part of the board finds the water already put in leeward motion, it follows that the latter parts of the board are in contact with particles already moving so fast to leeward that, unless they accelerate their leeward speed, they will experience no lateral pressure from the water. Hence, two effects must follow; the after-parts of the board will have less pressure on them than the fore-parts, and also the after-parts will be moving to leeward faster than the fore-parts. This is the explanation of the ardency produced by a long, parallel, middle body.

Other causes of ardency.

Another source of derangement between the centres of effort and resistance will be found in any deviation from the water-line, which may be produced in the change of shape in the vessel as she heels over from the pressure of side wind. If a full part of the ship comes into the water on heeling over, that part will cause its own special resistance, and, so far as it deviates from the true form, will cause an excess of pressure at that point, and a derangement of the centres of balance: it will, in fact, make the vessel behave as if she had a curved keel, concave to the wind. Another reason why heeling produces ardency, is that it forces the centre of effort of sail to leeward, so as to make the masts exert a horizontal leverage, to bring the ship's head into the wind. Apart from heeling, there is also a small element of ardency in the case of fore-and-aft sails, from their centre of effort being invariably to leeward. Theoretically, the bellying of square sails should tend in the same direction, but I believe that this cause is not appreciable in practice.

Ardency due to adhesion of water.

There is another cause of deviation which must take effect in all vessels, of whatever form, but I take it last, because its action is slight, and is not, except in the case of very great length of middle body (as noticed before), of sufficient consequence to rank as an element in the adjustment of the centres,—I mean, the resistance of the adhesive film of water on the skin of every ship. This adhesive film is scarcely a visible thickness at the bow; it increases uniformly with the distance from the bow towards the stern, where it is greatest: the invisible film seems to grow as it goes, by attaching to itself another and another outside film on each foot of progress, and, all added together, the entire film has a thickness of a foot or more on each side, at the stern. This may diminish the lateral resistance, but it seems just enough to give the vessel that degree of ardency, which is preferable to the smallest degree of the opposite quality; and when no other source of derangement than this remains, the naval architect may safely congratulate himself on having completed that part of his business satisfactorily. One other source of disturbance will always remain, which he can neither foresee nor prevent—the winds and the waves will always act irregularly on the ship. But when he has done the preadhesion of water.

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Shipbuilder must find centre of lateral resistance of ship;

It is the duty of the shipbuilder to make an exact calculation on the body of his ship, so that, when loaded in the water to its proper line, the lateral resistance to lee-way shall be found at its proper point in the length of the ship. This central balancing point he calls "the centre of lateral resistance," and it should be a little abaft the centre of the ship.

and then centre of effort of sail.

His next duty is to make an exact calculation of the sails of his ship, so that the pressure of the wind upon all the sails may have its central balancing point rightly placed in reference to the centre of resistance of the ship. This is called "the centre of effort of sail," and should be so adjusted as neither to be too near the bow, nor too far from it. In some pure wave-line vessels I have found it necessary to place the centre of lateral resistance of ship, and the centre of effort of sail, precisely one over the other; but, in the forms of ordinary sailing-vessels, it is found necessary to have the centre of resistance a little abaft the middle of the ship, and the centre of effort of sail a little forward of the middle. To bring the centre of resistance aft, a ship is generally trimmed two feet by the stern; and to carry the centre of effort forward, additional sail, beyond the quantity proper for a vessel on even keel, is carried on the bowsprit. By these means, a distance of about one-twentieth part of the length of the ship may be placed between these two centres, and in most ships this is sufficient for the purpose. I give below a table, showing the distance, to which trimming the ship by the stern will shift the centre of resistance backwards, and also the additional area of sail on the bowsprit, which will suffice to place an interval of one-twentieth of the ship's length between the centres.

Trim.

Trim depends more on commander than on constructor.

But, however exactly the naval architect may have designed his ship, the trimming of the sails and ship must remain essentially a part of the master's duty, because the trim of the ship is chiefly a question of stowage of cargo and disposition of weights; and as this is always varying in a steam-ship, and can always be ill or well done in a sailing-vessel, the original constructor of a ship, however wise, can never dispense with the watchfulness and judgment of the master mariner.

Centre of resistance may vary at different speeds.

There is another cause for constant watchfulness as to trim, in the fact that most ships shift their centre of lateral resistance forward, as their speed increases, and therefore require after-sail to be diminished, more than fore-sail, as the wind rises. The first duty, therefore, of an officer in command of a new ship, or starting on a fresh trim, is to determine the proper balance of ship and sail. He should shift weights forward and aft, until he finds the trim which will enable him to carry the proper sails; and, having done this, should carefully study how the quantity of sail must be adjusted in the various degrees of strength of wind, so as to measure this balance. It is in this way, that a skilful captain will often make a ship fast by trim alone, whereas an ignorant commander will fail to find out the good points in a ship, because he does not systematically look for them by studying her performance under every variety of trim at his command. In this way, the captain, even more than the naval architect, makes the character of his ship.

Summary.

The sum of what we know in regard to balance of body, and balance of sail and trim, is shortly as follows,—

The middle of the length of a ship is the balance-point or centre of lateral resistance of a ship, if she be nearly at rest, drifting to leeward, and if she be on even keel, with upright stem and stern-post.

Trim and rake compared.

Trim of ship by the stern shifts the centre of lateral resistance from the middle towards the stern. An inch of trim to a foot of draft shifts the centre of lateral resistance abaft the middle hy one hundred and forty-fourth part of the length of the ship. Or the excess aft, represented by a fraction of the draft amidships (say one-sixth), multiplied by one-twelfth of the ship's length, gives the shift abaft caused by trim. Raking the stern-post and rounding the stem also shift the centre of lateral resistance forward or aft. Raking the stern-post shifts this centre forwards one quarter of the rake. Rounding the stem, so as to make it a quarter of a circle, shifts the centre aft by about one-tenth of the draft at the stem.

In the most ordinary shape of ships these last counteract each other, and if the draft fore and aft be nearly equal, the centre of lateral resistance at rest is in the middle of the length.

If we wish to find what amount of trim will balance a given amount of rake of stern-post we must use the approximate formula,—

$$\frac{\text{trim}}{\text{rake}} = 3 \text{ times } \frac{\text{draft amidships}}{\text{length}}$$

or else refer to the following table, which has been calculated from this formula:—

one-sixth), multiplied by one-twelfth of the ship's length, gives the shift abaft caused by trim. Raking the stern-post and rounding the stem also shift the centre of lateral resistance forward or aft. Raking the stern-post shifts this centre forwards one quarter of the rake. Rounding the stem, so as to make it a quarter of a circle, shifts the centre aft by about one-tenth of the draft at the stem.

In the most ordinary shape of ships these last counteract each other, and if the draft fore and aft be nearly equal, the centre of lateral resistance at rest is in the middle of the length.

If we wish to find what amount of trim will balance a given amount of rake of stern-post we must use the approximate formula,—

$$\frac{\text{trim}}{\text{rake}} = 3 \text{ times } \frac{\text{draft amidships}}{\text{length}}$$

or else refer to the following table, which has been calculated from this formula:—

TABLE SHOWING RAKE OF STERN-POST REQUIRED TO BALANCE A GIVEN TRIM, OR DIFFERENCE OF DRAFT FORWARD AND AFT.

Inches of difference of trim to every foot of draft amidships.	RAKE OF STERN-POST.			Inches of difference of trim to every foot of draft amidships.	RAKE OF STERN-POST.		
	In inches, to every foot of length of vessel.	In fraction of length.	Decimal fraction of length.		In inches, to every foot of length of vessel.	In fraction of length.	Decimal fraction of length.
0·5	·17	$\frac{1}{72}$	0·01389	3·5	1·17	$\frac{7}{72}$	0·09722
1	·33	$\frac{1}{36}$	0·02778	4	1·33	$\frac{1}{9}$	0·11111
1·5	·50	$\frac{1}{24}$	0·04167	4·5	1·50	$\frac{1}{8}$	0·12500
2	·67	$\frac{1}{18}$	0·05556	5	1·67	$\frac{5}{36}$	0·13889
2·5	·83	$\frac{5}{72}$	0·06944	5·5	1·83	$\frac{11}{72}$	0·15278
3	1	$\frac{1}{12}$	0·08333	6	2	$\frac{1}{6}$	0·16667

The mere statical resistance of a thin plate, floating vertically, to lateral motion, is collected at its centre of pressure, not at its actual centre of gravity. But there is less practical error in calculating by means of the latter, for several reasons; among which one is, that when lateral motion has once begun, the water is heaped

Statical resistance of thin plate not in point.

up in front of the plate, while a hollow is formed behind it. This creates a resistance at the surface, which more than compensates for the increased pressure of greater depths. In rapid motion, the centre of lateral resistance is found, in practice, to be considerably above the centre of gravity of the longitudinal section, instead of below it, as is the centre of hydrostatic pressure.

Effect of motion.

But the centre of lateral resistance of a ship with a full bow and water-line forward is shifted forward, from the moment she has speed, because the resistance on the lee-bow is greater than on the weather-bow, and because the resistance of water to a bow in motion is much greater than to the stern. The leeward motion also makes the resistance fall more directly on the bow than on the stern. Next, the lee-bow is altered in form when the ship heels over by the wind and becomes fuller than the weather-bow. Hence such vessels, as they increase in speed, experience increasing pressure on the bow and not on the stern, thus driving the bow up into the wind, and allowing the stern to drift to leeward.

This disturbance of balance of the lateral resistance of the body of the ship has to be met in two ways. The ship has to be trimmed by the stern, which helps to bring back the centre of lateral resistance to the middle. Or it may be met in another way—more sail may be carried on forward to counteract this effect.

Met by trimming sail.

The shift of centre of effort of all the sails forward, is the mode of correcting this disturbance of the centre of resistance, which is most employed by naval architects; but it is not possible to make this adjustment absolute beforehand; each form of ship has its own peculiarity in this respect. One ship will balance her sail with its centre exactly on the middle of the water-line, another will carry it one-tenth of her length forward of the middle.

Proper balance-point for sail.

As a general rule, I should say, that any vessel, having her water-lines of bow convex, may be expected to carry her balance point of ship to balance point of sail, whether going free or on a wind, one-twentieth part of her length before her middle, reckoned on the water-line and nearly on even keel. If the centre of the longitudinal vertical plane be much out of the middle of the length, the centre of effort must follow it.

Only in a sharp hollow-bowed vessel, built on the pure wave-line form, this balance of body and sail is perfect and exact, and undergoes no disturbance, so that the centre of effort of the sail may be placed exactly over the centre of gravity of the longitudinal vertical plane.

CHAPTER XVI.

ON SYMMETRY, FASHION, AND HANDINESS OF SAILS.

Hitherto we have studied sails with reference only to their effect on the ship, in so far as concerns the work of the naval architect. Whether they are well proportioned in size to the ship; whether they are well balanced, so as to leave the ship free in her movements; whether they are so proportioned in dimension, that they drive, without overpowering, the ship; whether they can be varied in quantity to any extent, withont derangement of balance, and always leave the ship under command of the helm: when these questions are satisfactorily answered, then the first great requisites of the naval constructor are accomplished. But other things are demanded of us, besides this first essential, their use to the ship. We must please the sailor in the figure, distribution, and cut of his sails. They must be eye-sweet; they must not merely be purpose-like. Their fashion must please the sailor's fancy. Beyond this, they must fit his personal convenience and use. They must sit well, stand well, draw well, be easily set, easily worked, easily reefed, easily taken in: in short, be conveniently, easily, and safely handled. I think it quite right that, on this point, the will of the sailor should rule the design. The quantity and balance of sail is in the vocation of the naval architect; but the symmetry, fashion, and cut of his sails, is in the vocation of the seaman, not of the landsman. What the naval architect has to consider is, how he shall give the seaman all he wants in his fashion, without compromising the other conditions on which the ship is designed. This requires skill; and for this purpose all we have said about balance of sail and of ship, forms an excellent basis, on which may be grafted any amount of fashion and of fancy, of fitness and of handiness. Fashion of sail a question of seamanship.

Let us suppose a full-rigged ship, with three square-rigged masts, to have been designed; and the place of all the chief sails, their areas and their dimensions, to be laid down on a sail-draft, by the rules already given; and the question now to be raised is, How may the fashion of the sails be altered, without disturbing their balance, or changing their quantity?

Our plates show the different fashion of square sail on eight masts of eight different ships, three different sail areas being shown on each mast; one, the standard area in four sails, the other in three; and the fashion adopted for the same sail in each named ship. From these, the great variety in fashion, for the same area, is manifest. Plates XV. and XVI.

For every square sail on every mast there arise three main questions: 1st. Taper of sail, or diminution of personal convenience and use. They must sit well, stand well, draw well, be easily set, easily worked, easily reefed, easily taken in: in short, be conveniently, easily, and safely handled. I think it quite right that, on this point, the will of the sailor should rule the design. The quantity and balance of sail is in the vocation of the naval architect; but the symmetry, fashion, and cut of his sails, is in the vocation of the seaman, not of the landsman. What the naval architect has to consider is, how he shall give the seaman all he wants in his fashion, without compromising the other conditions on which the ship is designed. This requires skill; and for this purpose all we have said about balance of sail and of ship, forms an excellent basis, on which may be grafted any amount of fashion and of fancy, of fitness and of handiness.

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For every square sail on every mast there arise three main questions: 1st. Taper of sail, or diminution of the head of each sail, compared with width at the foot. 2nd. Proportion of height to width, or spread of sail in proportion to hoist. 3rd. Subdivision of sails on a mast.

I. *Diminution of the head of the sails on a given mast.*—The sails on the same mast may all have the same taper, diminishing in one straight line; or they may vary in taper. Taper of sails.

It is perhaps, most obvious, that whatever reason exists for a certain taper in a given sail, will apply equally to that above it. That the sails on all three masts should have the same taper for one and all, seems self-evident. I think, also, there is a general preference for having one proportion for the diminution of the head of the sail running through all the high sails of the same mast, especially where the subdivisions are numerous. But, on the other hand, it is a frequent practice to narrow most the heads of the highest sails.

the additional sails be so placed and proportioned, as not to disturb the original balance. By means of a bowsprit, we may carry the sail forward until it ends in a point, but we must take care to extend the sail also backward (*see* fig. E), sufficiently far to countervail the addition in front, otherwise the wind will tend to make the ship sheer round, and the balance will be destroyed. The whole sail will thus become one large triangle. This form is extremely convenient for vessels carrying fore-and-aft sail, but these additional sails fore and aft may be, and indeed are, mere patches. These patches, however, are often used simply as balancing, or directing, or steering sails, to steady the vessel, without any regard to their propelling power. Such a triangular sail is sometimes carried by a single mast, and sometimes divided, in the same manner as lug-sails; and it is curious to observe, how differently the whims of the sailors of these vessels may be indulged, as to the mode of supporting and carrying sails; for in a triangular sail, as shown in F, I have seen the single sail equally well carried by an upright mast in the middle of the boat, by a mast in the bow raking violently aft, and by a mast aft raking as violently forward; the one condition only being fulfilled, of leaving the balance of sail unchanged.

Fore-and-aft sails sometimes used only for balance.

Centre of effort of a sail.

It is well known, that all triangles on the same base, having the same height, contain the same area, and when once we have obtained a triangular area of sail, we may change that in shape as we please, provided we keep it of the same height. What we have to notice, however, is, that as we change the shape of the triangle, we shift with it the place of effort of the sail: thus, the two triangular sails in figure G are of equal area, but the centre of effort has been shifted forward by the change of shape.

The balance of sail will be destroyed, if, in dividing the sail area, we do not take care, that in any new distribution we make, the place of centre of effort is not shifted by that distribution; not only must the portions, cut off from one part of the sail-area, be supplied in quantity by another, but we must also see, that in tbeir new positions the new parts do not gain or lose power of balance; power of balance being effectual distance: we must, therefore, learn to calculate the exact effect of sails placed at different distances.

How found in triangular sails.

To calculate the balance of sail, we have two simple and convenient principles. A triangular sail has its centre of effort in the line which joins any of its corners to the middle of the opposite side, and is nearer to the side than to the corner, in the proportion of 1 to 2; so that, by dividing the line into three equal parts, and marking the division which lies nearest the side, you mark the centre of effort of the sail; or it may be found by drawing lines from two corners to the middle points of the opposite sides: it will then be at the of equal area, but the centre of effort has been shifted forward by the change of shape.

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Now it fortunately happens that the shapes of all sails, if not triangles, can be divided into triangles merely by drawing a line through two opposite corners; each part of the sail can thus have its centre of effort separately found.

How compounded in sails of another shape, or for two sails.

Having thus found the centres of effort of all the sails, or of all their separate parts, the question next in order is: How do we find the joint effort or effect of any pair, or any uumber, of triangular sails, or parts of sails? This we do by the principle of balance, which is well known to be as follows:—In order that two equal sails may balance, they must be at equal distances from the point round which they are iutended to balance, otherwise the one at the greatest distance will sway the other out of its place; hence, equal sails will only balauce at equal distances. The equal distances are to be reckoned from the centres of gravity of the respective sails; if, therefore, there are only two equal sails in a ship, the balance is easy, for we have only to place their centres equidistant from the balance-point in the ship, and the sails will balance. The joint centre of effort of two equal sails, therefore, lies in the line of, and half-way between, their respective centres of effort.

But we may have a pair of unequal sails, and unequal in any proportion: say, 2 to 3. The way to balance them is, to give the less sail the longer end of the balance, and to give the longer end the same preponderance in length over the shorter, as the larger sail has over the smaller: thus, the longer distance, combined with the smaller area of sail, compensates the larger area, combined with the shorter distance. To see that they are equal, we multiply the sail area in the one by its distance, and the sail area in the other by its distance; and when these products are equal, we have the balance sought.

Suppose, on this principle, we want to find the centre of effort of a sail composed of two triangular parts: we already know how to find the centre of effort of each,—we join these centres by a line, we divide this whole line into as many equal parts as there are fathoms of area in the whole sail, and we give to the lesser portion a greater number of these parts, and to the greater portion a less uumber, dividing the line iu the inverse proportion of the areas: the point of division is the joint centre of effort of the sail.

If, now, there were a uumber of sails, some on one side, and some on the other, of an intended balance-point, and the question were asked, whether they balauce, we should multiply the areas of all the sails by their distance from the balance-point, and, if the sum of the products on the one side were equal to the sum of the products on the other side, there would be a balance. To make a balance, therefore, we have merely to coutrive that the sums of the products of the sail areas on opposite sides, by their distances from the balauce-points, shall be equal.

For a number of sails.

It is plain, therefore, that to bring about a balance where it does not exist, we may either substitute a larger sail on the wanting side for a smaller one, or we may shift the place of sail nearer to, or farther away from, the centre, as required. A ship of which the sails are ill balanced may be rectified by the captain, by the different quantity of sail he may choose to set; or it may be rectified, on a larger scale, by shifting the place of the masts, or, in a smaller degree, by causing a mast to rake more or less forward or aft. Where these remedies may be impossible or inconvenient, the centre of resistance of the body of the ship may be shifted towards the centre of effort of the sail, by trimming the vessel a little more forward, or aft; as it is plain, that trimming by the stern will bring it aft, and trimming by the head will bring it forward.

How balance may be rectified.

We may now proceed to establish proportions, according to which the masts and sails of a ship may be divided and distributed. I will take for this purpose a vessel which has three masts, and I will suppose the vessel to be of a pure wave form, to be on even keel, her length to be divided into ten equal parts, and her bowsprit to exteud so as to bring the centre of the jib 5·41 of such tenth parts beyond the stem, the extremity of the driver being one-tenth part beyond the stern. For the distribution of sail, make the following division,—

Place of masts.

Divide the sail area into 24 equal parts: 7·071 of these are for the foremast, 10 for the mainmast, 1·65 for the driver, 3·35 for the other sails ou the mizenmast, and the remainder, or 1·929, for the jib. The place of the mizenmast is one-tenth from the stern, of the foremast two-tenths from the bow, and of the mainmast three-tenths from the mizen, or oue-tenth from the middle, having four-tenths between the fore and mainmast.

Distribution of sail on masts.

Reckoning from the centre of lateral resistance of the vessel, which, ou an even keel, is the middle of her length, we have the following arrangements,—

Sails.	Quantities.		Effective distances.		Total effects or total efforts.
Driver . .	1·65	×	5	=	8·25
Mizen . .	3·35	×	4	=	13·40

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Reckoning from the centre of lateral resistance of the vessel, which, on an even keel, is the middle of her length, we have the following arrangements,—

Sails.	Quantities.		Effective distances.		Total effects or total efforts.	
Driver . .	1·65	×	5	=	8·25	
Mizen . .	3·35	×	4	=	13·40	
Main . .	10	×	1	=	10	
					31·65	after moments.
Fore . .	7·071	×	3	=	21·213	
Jib . .	1·929	×	5·41	=	10·436	
Total . .	24				31·649	fore moments.

The explanation of this table is simple; the five parts which form the mizen-sails consist of 3·35 of the square or upper sails, and the other 1·65 of the driver, which driver has its centre of effort one division further aft than the upper sails: the parts which form the upper sails are therefore multiplied by 4, and give an effect of 13·4, while the parts which form the driver act at a distance of 5, and give an effect of 8·25.

The 10 parts which form the mainmast sail area are only at one division from the centre, and give an effect of 10; therefore the total effect of the after-sails is represented by figure 31·65.

The 7·071 parts of sail on the foremast are 3 divisions forward of the middle, and therefore give an effect of 21·213, while the 1·929 parts which form the jib, acting of 5·41 tenths from the middle, give an effect of 10·436; the foremast and the jib making together an effect of 31·649.

This gives the balance of sail we want; and it may be observed that the jib, though small, has as much absolute effect on the balance of sail as all the sail on the mainmast, nay, rather larger, while the mizen, though comparatively small, actually balances the foremast. It is convenient to remember, in working a ship, that you may use the sail on the mainmast and the jib as a balance for one another; while, for other purposes, you may use the sails on the mizen and on the foremast, also as balancing each other; either set alone could work

Jib balances sail on mainmast.

Foremast sails balance after-sails.

the ship. It is also worthy of notice, that the jib may be made to balance exactly the upper sails on the mizen. It will thus be seen that the total moments of the sails forward are represented by 31·649; the total effect of those abaft by 31·65; and the total number of component parts of sail are represented by 24.

Proportions for sails.

It now remains to be considered how to proportion the various sails on these different masts.

1st. Of the 5 parts of sail on the mizen, 1·65 go to the driver, and the remainder is divided between topsail, topgallant-sail, and royal, in the following proportion,—Mizen-topsail, 1·518; mizen-topgallant, 1·073; and mizen-royal, 0·759.

2nd. Of the 10 parts of sail which go to the mainmast, 3·3 form the main-course, 3·035 form the maintop-sail, 2·147 form the main-topgallant-sail, and 1·518 the main-royal.

3rd. Of the 7·071 which go to the foremast, 2·3333 form the fore-course, 2·147 form the foretop-sail, 1·518 form the fore-topgallant-sail, and 1·073 form the fore-royal—

Masts.	Sails.						
Mizen	Driver	1·65 × 5	= 8·25	21·65	31·65
	Topsail	1·518 × 4	= 6·072		
	Topgallant-sail . .	1·073 × 4	= 4·292		
	Royal	0·759 × 4	= 3·036		
Main	Course	3·3 × 1	= 3·3	10	
	Topsail	3·035 × 1	= 3·035		
	Topgallant-sail . .	2·147 × 1	= 2·147		
	Royal	1·518 × 1	= 1·518		
Fore	Course	2·333 × 3	= 6·999	21·213	31·649
	Topsail	2·147 × 3	= 6·441		
	Topgallant-sail . .	1·518 × 3	= 4·554		
	Royal	1·073 × 3	= 3·219		
	Jib	1·929 × 5·41	= 10·436		

Proportions for masts.

But we have got a third question to solve. We have got the proportion of sail on each mast; we have got the proportion of area on each sail, and on each mast; but we have not got the proportionate dimensions of each mast, which will enable them to carry their respective sails.

In a three-masted ship it is necessary, both for symmetry of appearance and for balance of sail, that the proportion of every sail on each mast should be tolerably similar: for example, on the bigger mast, there should be a bigger topsail; on the smaller mast, a smaller topsail, and so on. It is also desirable, that the sizes of

Main	Topsail	3·035	×	1	=	3·035	10	
	Topgallant-sail . .	2·147	×	1	=	2·147		
	Royal	1·518	×	1	=	1·518		
Fore	Course	2·333	×	3	=	6·999	21·213	31·649
	Topsail	2·147	×	3	=	6·441		
	Topgallant-sail . .	1·518	×	3	=	4·554		
	Royal	1·073	×	3	=	3·219		
	Jib	1·929	×	5·41	=	10·436		

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The following proportion of sails will accomplish all this. If we take the three masts to have four sails, all similar, then we have the proportion above given; namely,—

Areas of sail—mizen,	5	fore, 7·071	main, 10
Being in the proportion of . . .	1	1·4142	2

In order to make up this proportion, it is merely necessary that all the sails on the three masts should be in, as near as possible, the following proportion,—

5 . . . . 7·071 10

The sails on all the masts will all have the proportion required,—

1 . . . . 1·4142 2

Proportions for yards.

For example, when the mizen-yard has for its breadth of sail 50 feet; then fore-yard 70·71 feet, main-yard 100 feet, or in that proportion.

The corresponding topsail-yards should he in the same proportion, namely,—

	35·35	50	70·71
the topgallant-yards in the proportion . . .	25	35·35	50
and the royal-yards in the proportion . . .	17·67	25	35·35

It is obvious, also, that the lengths of those parts of the masts and spars which carry sail should bear to one another the similar ratio of . . . 5 . . . . 7·071 10

or, 1 . . . . 1·4142 2

With these general proportions in view, let us now proceed to complete the arrangement of sail on a given ship, say of 550 tons burthen, whose length on the water-line is 150 feet, and draft on even keel 16 ft. 8 in. Taking six times the draft of water, or 100 feet, this gives the height of the equivalent sail area 100 feet; which, by a length of 150 feet, gives us a total sail area of Specific example.

$$150 \times 100 = 15{,}000 \text{ feet area.}$$

First—to place the masts, divide length in water-line into 10 equal parts. Example continued.

Distance of mizen from aft	= ·1 of 150 =	15 feet.
„ of foremast from fore . . .	= ·2 of 150 =	30 „
„ of mainmast from mizen . .	= ·3 of 150 =	45 „
„ of mainmast from foremast .	= ·4 of 150 =	60 „
		150 „

Second—to proportion the sail-area on each mast.

Mizen . . five twenty-fourths of 15,000	= 5	× 625	=	3125
Fore	= 7·071	× 625	=	4419·375
Main	= 10	× 625	=	6250
Jib	= 1·929	× 625	=	1205·625
				15·000

Third—to proportion the sails on each mast.

Mizen	Driver	1·65	× 625	=	1031·25	3125·00
	Topsail	1·518	× 625	=	948·75	
	Topgallant-sail . .	1·073	× 625	=	670·625	
	Royal	0·759	× 625	=	474·375	
	Course	2·303	× 625	=	1458·125	
	Topsail	[illegible]	× 625	=	[illegible]	

Fore	. . . .	= 7·071	× 625	=	4419·375
Main	. . . .	= 10	× 625	=	6250
Jib	. . . .	= 1·929	× 625	=	1205·625
					15·000

Third—to proportion the sails on each mast.

Mast	Sail					Total per mast	Total
Mizen	Driver	1·65	×	625	= 1031·25	3125·00	15,000
	Topsail	1·518	×	625	= 948·75		
	Topgallant-sail . .	1·073	×	625	= 670·625		
	Royal	0·759	×	625	= 474·375		
Fore	Course	2·303	×	625	= 1458·125	4419·375	
	Topsail	2·147	×	625	= 1341·875		
	Topgallant-sail . .	1·518	×	625	= 948·75		
	Royal	1·073	×	625	= 670·625		
Main	Course	3·3	×	625	= 2062·5	6250·00	
	Topsail	3·035	×	625	= 1896·875		
	Topgallant-sail . .	2·147	×	625	= 1341·875		
	Royal	1·518	×	625	= 948·75		
					Jib = 1205·625		

Or in other words,

	Driver.		Forecourse.		Maincourse.
	1·65	. . . . . .	2·333	. . . . . .	3·3
Or in the proportion of	1	. . . . . .	1·4142	. . . . . .	2
	Mizen-topsail.		**Fore-topsail.**		**Main-topsail.**
	1·518	. . . . .	2·147	. . . . . .	3·035
Or in the proportion of	1	. . . . .	1·4142	. . . . . .	2
	Mizen-topgallant-sail.		**Fore-topgallant-sail.**		**Main-topgallant-sail.**
	1·073	. . . . .	1·518	. . . . . .	2·147
Or in the proportion of	1	. . . . .	1·4142	. . . . . .	2
	Mizen-royal.		**Fore-royal.**		**Main-royal.**
	0·759	. . . . .	1·073	. . . . . .	1·518
	1	. . . . .	1·4142	. . . . . .	2

Example continued.

Again,—

	Topsail.	Topgallant-sail.	Royal.
Mizen	1·518	1·073	0·759
Or in the proportion of	2	1·4142	1
Main	3·035	2·147	1·518
Or in the proportion of	2	1·4142	1
Fore	2·147	1·518	1·073
Or in the proportion of	2	1·4142	1

Now to get the length of the yards, the lower yards are immediately found by taking the square root of twice the area of the courses; and for the mizenmast, as the area of the driver is equal to the same area as that of a course, if there had been one, on the crossjack-yard, twice the square root of the area of the driver must be taken. We find for

The length of the mainyard	64·23,	or in the proportion of	1
" foreyard	54	"	·8409
" crossjack-yard	45·41	"	·7071

These proportions give at once the length of yards and hoist of sail; for, multiplying the length of the mainyard by 0·8409, we get the length of the foreyard and maintopsail yard; by multiplying the length of the foreyard or maintopsail-yard by 0·8409 we get the length of the crossjack-yard, foretopsail-yard, and main-topgallant-yard, and so on, always excluding yard-arms. These same proportions answer for the hoist of sail; or, in other words, half the length of the mainyard is the hoist of the maintopsail; half the length of the maintopsail-yard is the hoist of the topgallant-sail; half the length of the main-topgallant-yard is the hoist of the mainroyal. It will, therefore, plainly be seen, that we shall have, with this arrangement, one yard of the length of the mainyard, two yards of the length of the maintopsail-yard, three yards of the length of the main-topgallant-yard, three yards of the length of the mainroyal-yard, two yards of the length of the foreroyal-yard, and one yard of the length of the mizenroyal-yard. Working the above quantities out for the vessel, whose areas of sails we have calculated, we find for the length of—

Mainyard = 64·23	Foreyard = 54	Mizencross-jack = 45·41
Topsail-yard = 54	Topsail-yard = 45·41	Topsail-yard = 38·18
Topgallant-yard = 45·41	Topgallant-yard = 38·18	Topgallant-yard = 32·41

These proportions give at once [illegible] length of yards and hoist of sail, [illegible], multiplying [illegible] mainyard ~~by 0·8409, we get the length of the foreyard and maintopsail~~ yard; by multiplying the length of the foreyard or maintopsail-yard by 0·8409 we get the length of the crossjack-yard, foretopsail-yard, and main-top-gallant-yard, and so on, always excluding yard-arms. These same proportions answer for the hoist of sail; or, in other words, half the length of the mainyard is the hoist of the maintopsail; half the length of the maintopsail-yard is the hoist of the topgallant-sail; half the length of the main-topgallant-yard is the hoist of the mainroyal. It will, therefore, plainly be seen, that we shall have, with this arrangement, one yard of the length of the mainyard, two yards of the length of the maintopsail-yard, three yards of the length of the main-topgallant-yard, three yards of the length of the mainroyal-yard, two yards of the length of the foreroyal-yard, aud one yard of the length of the mizenroyal-yard. Working the above quantities out for the vessel, whose areas of sails we have calculated, we find for the length of—

Mainyard	= 64·23	.	Foreyard	= 54	.	Mizencross-jack	= 45·41
Topsail-yard	= 54	.	Topsail-yard	= 45·41	.	Topsail-yard	= 38·18
Topgallant-yard	= 45·41	.	Topgallant-yard	= 38·18	.	Topgallant-yard	= 32·41
Royal-yard	= 38·18	.	Royal-yard	= 32·41	.	Royal-yard	= 27·26

And when, with these figures, the areas of the different upper sails are calculated, it will be found that the quantities found in this manner, and the quantities found in the first manner, will agree with great precision.

It will be seen that, with the foregoing arrangement, we get a perfect balance; that is, that the centre of sails falls exactly in the same perpendicular with the centre of lateral resistance. Now, in some ships, it is preferable to have tbe centre of effort some distance forward of the centre of lateral resistance. This is easily accomplished by means of the jib.

How jib may be used to alter balance of sail.

The centre of the jib, in our calculations, was situated at 5·41 from the centre or middle division. Now, by only shiftiug its centre to six divisions from the middle, which in our vessel of 150 length would be 90 feet, the centre of effort would be brought forward 5 feet. This may seem difficult to do, as the masts are fixed, and the foretopmast-stay cannot be shifted: it therefore only remains to alter the shape of the jib. This is done in the following manner,—Erect a perpendicular line, on the sixth division from the middle of the water line; then, on this perpendicular, the centre of the jib will be situated. Lengthen this perpendicular till it meets the foretopmast-stay; then lay off from this intersection, equal distances, up and down along the stay, as far as convenient; the sum of these two distances will form one side of the jib. The area of the jib being given, divide this area by half the side, and with the qnotient as length, draw a line parallel to the foretopmast-stay till it intersects the perpendicnlar line. Join this point with the two extremities on the jib-stay, and we shall have a shape of jib of the given area, and with its centre falling exactly at the sixth division from the middle, or one-tenth of the length beyond the stem: this construction has repeatedly been done in Table, page 88, to get the different balances required. But this degree of accuracy is much greater than is required for practice; and it is necessary to guard against the attempt to fix these points in the design too closely before taking into consideration a multitude of practical points of convenience, use, and taste, which go to regulate the dimensions of sails. In the first place, it must never be forgotten that nearly all ships carry weather-helm, and that they carry more weather-helm in proportion as the wind blows stronger. This point has been fully explained in Chapter XIV.

It is to be observed, that the design of the sails having been made in proper balance, any change, made to correct defects in the form of the body, should not be allowed to derange either the proportions or places of sails; but for this purpose the whole sails should be removed to their new place, and not shifted with respect to each other, unless due regard be had to maintaining their balance. If alterations made, balance must be maintained.

Another point for consideration is, that masts are made to rake, instead of standing upright: it must not be forgotten that rake may shift the relative distance of the sails. Convenience of ship sometimes dictates sail to be used.

A further point is, that the convenience of the ship herself may interfere with the disposition of sails. A high forecastle will shorten the foot of the foresail. A poop, and the convenience of passengers, seriously interfere with the mizen; for the latter reason, chiefly, a driver has been substituted for the square sail or course on the third mast, although there are cases in which it would be convenient to carry that sail. These are points that must, on no account, be neglected.

Perhaps the most important point, that can be kept in view in the study of balance of sail, balance of body, placing of masts, proportion of spars, and subdivision of sails, is this, that in all circumstances the ship should be able to carry the greatest quantity of sail with the least possible action of rudder. In a perfect wave-form, perfectly balanced, this has been done, and in a fast-sailing clipper it is vital. In such a vessel the whole of the sails I have mentioned would be carried, whether the wind was light or fresh, without retarding the ship by the action of the helm. When it came to blow hard, it would only be necessary to take in the three topgallant-sails, and the rest of the sails would remain in perfect balance; blowing harder, the topsails would all be reefed, and still balance; blowing yet harder, the driver, the jib, the forecourse and the maincourse, might all be taken in; and she would still balance under the foretopsail, the maintopsail, the mizentopsail, and a storm-jib. Importance of balance of sail.

Thus, in a wave-vessel, even in heavy weather, the captain would still find his ship handy, fast, and under perfect command; but, if the vessel were not a wave-vessel, the following changes would take place ... Balance of sail perfect only in to each other, unless due regard be had to maintaining their balance.

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Convenience of ship sometimes dictates sail to be used.

A further point is, that the convenience of the ship herself may interfere with the disposition of sails. A high forecastle will shorten the foot of the foresail. A poop, and the convenience of passengers, seriously interfere with the mizen; for the latter reason, chiefly, a driver has been substituted for the square sail or course on the third mast, although there are cases in which it would be convenient to carry that sail. These are points that must, on no account, be neglected.

Importance of balance of sail.

Perhaps the most important point, that can be kept in view in the study of balance of sail, balance of body, placing of masts, proportion of spars, and subdivision of sails, is this, that in all circumstances the ship should be able to carry the greatest quantity of sail with the least possible action of rudder. In a perfect wave-form, perfectly balanced, this has been done, and in a fast-sailing clipper it is vital. In such a vessel the whole of the sails I have mentioned would be carried, whether the wind was light or fresh, without retarding the ship by the action of the helm. When it came to blow hard, it would only be necessary to take in the three topgallant-sails, and the rest of the sails would remain in perfect balance; blowing harder, the topsails would all be reefed, and still balance; blowing yet harder, the driver, the jib, the forecourse and the maincourse, might all be taken in; and she would still balance under the foretopsail, the maintopsail, the mizentopsail, and a storm-jib.

Balance of sail perfect only in wave-form.

Thus, in a wave-vessel, even in heavy weather, the captain would still find his ship handy, fast, and under perfect command; but, if the vessel were not a wave-vessel, the following changes would take place. As soon as it came to blow fresh, the driver, which is a most powerful sail, would be found to cause excessive weather-helm; and, stopping the way of the ship, would soon have to be taken in: but as that would spoil the balance, it would be necessary at the same time to reef the foretopsail, and so to lose way, and also to take in the jib, which would at once reduce very seriously the way of the ship, as it would be the want of balance, and not stress of weather, which did it. If it came to blow hard, it would soon be necessary to take all sail off the mizen, except, perhaps, a small storm-sail for lying-to. In ships of this class nothing but experience will tell, under what sails the ship will balance, and what she will not carry; but one thing is certain, that in light winds and in strong ones the balance will be entirely different, which is not the case in the pure wave-form.

Description and Use of the following Tables.

Description of Tables.

It is to be noticed, in using the following tables, that the centre of the sails is taken as being in the line of the mast, and all the sails are braced round in a line parallel to the keel: next, that where length of yard is spoken of, only that part of the yard is included, which is covered by spread of sail: thirdly, that length of ship is taken on the load-water line and middle of ship, at middle of load-water line. But care must be taken, that when the centre of resistance of the ship is shifted aft by trim, or is shifted forward by the resistance of the water to the bow, when under way, the centre of effort shall also be shifted, so as to maintain the balance. It is known, that ships with full bows have their centre of lateral resistance shifted forward from the middle, as much as one-twentieth of the length of load-water line. This shifted point must then be considered the middle point; and the distance from this shifted point to the bow-end of the water-line must be considered as half the length, and the distribution of sail must be made on this new middle and reduced length, instead of on the true middle and true length of load-water line.

When a given sail area is to be carried on a given ship, the following tables show the dimensions and distribution of balancing sails, as described in the preceding chapter. The Classification Table consists of a series of examples of balanced sails on twelve different sizes of ship. The largest table, on three pages, enables the constructor to determine the dimensions of spars and sails for his ship, for any given amount of sail area, by simple inspection.

The table of Balance of Sail, with four square sails on each mast, and jib to balance, shows how, when a vessel is full-rigged, or all standard sails are set, and different sets of sails are successively taken in, the balance may still be kept by setting a certain jib of a certain area, its shape depending upon the construction which is necessary, and which has been mentioned on page 84. A similar explanation applies to the corresponding table, for three square sails on each mast.

When the form of a ship is not the pure wave-form, but such as to shift the centre of resistance forward from the true middle, when the ship is at speed, then this shifted centre must be taken as the true middle, and the masts and sails must be distributed on both sides, as if it were the true middle, and the ten divisions of length must be taken as extending, one half from the bow to this shifted middle, and the other half to an equal distance astern of the shifted middle.

BALANCE OF SAIL.

I.

AREAS AND POWERS OF SAILS WITH FOUR YARDS ON EACH MAST.

Six times the area of the immersed longitudinal section is taken as standard sail area of the ship, of which for—

The area of all the square sails on the Mainmast	$= \frac{10}{24}$	of the whole area	
" " " " Foremast	$= \frac{7·071}{24}$	" "	
" " " " Mizenmast	$= \frac{3·35}{24}$	" "	$= \frac{24}{24}$
" " " " Driver	$= \frac{1·65}{24}$	" "	
" the " " Jib	$= \frac{1·929}{24}$	" "	

or,

The area of all the square sails on the Mainmast	= 0·4167	of the whole area	
" " " " Foremast	= 0·2946	" "	
" " " " Mizenmast	= 0·1396	" "	= 1
" the " " Driver	= 0·0687	" "	
" " " " Jib	= 0·0804	" "	

The powers of these quantities are for the Main area 1

" " " " Fore area	3
" " " " Mizen area	4
" " " " Driver ...	5
" " " " Jib	5·41

And the moments from the middle of the water-line are—

Driver.	*Mizen.*	*Main.*	*Fore.*	*Jib.*
1·65	3·35	10	7·071	1·929
×	×	×	×	×
5	4	1	3	5·41
=	=	=	=	=
8·25	13·40	10	21·213	10·436
		13·40	10·436	
		8·25		

After-moments 31·65 = 31·649 Fore-moments

The area of the Maincourse is	= 0·1375	of the whole area	
" " Maintop-sail	= 0·1265	" "	
" " Maintop-gallant sail	= 0·0895	" "	
" " Main-royal sail	= 0·0632	" "	
" " Fore-course	= 0·0972	" "	
" " Foretop-sail	= 0·0895	" "	
" " Foretop-gallant sail	= 0·0632	" "	= 1
" " Fore-royal sail	= 0·0447	" "	
" " Mizentop-sail	= 0·0632	" "	
" " Mizentop-gallant sail	= 0·0447	" "	
" " Mizen-royal sail	= 0·0317	" "	
" " Driver	= 0·6687	" "	
" " Jib	= 0·0804	" "	

The area of the Maincourse is	= 0·1375 of the whole area		= 1
" " Maintop-sail	= 0·1265	" "	
" " Maintop-gallant sail	= 0·0895	" "	
" " Main-royal sail	= 0·0632	" "	
" " Fore-course	= 0·0972	" "	
" " Foretop-sail	= 0·0895	" "	
" " Foretop-gallant sail	= 0·0632	" "	
" " Fore-royal sail	= 0·0447	" "	
" " Mizentop-sail	= 0·0632	" "	
" " Mizentop-gallant sail	= 0·0447	" "	
" " Mizen-royal sail	= 0·0317	" "	
" " Driver	= 0·6687	" "	
" " Jib	= 0·0804	" "	

AREAS AND POWERS OF SAILS WITH THREE YARDS ON EACH MAST.

Six times the area of the immersed longitudinal section is taken as standard sail area of the ship, of which for—

The area of all the square sails on the Mainmast	= $\frac{10}{24}$	of the whole area	$= \frac{24}{24}$
" " " " Foremast	= $\frac{7·071}{24}$	" "	
" " " " Mizenmast	= $\frac{3·06}{24}$	" "	
" the " " Driver	= $\frac{1·94}{24}$	" "	
" " " " Jib	= $\frac{1·929}{24}$	" "	

or,

The area of all the square sails on the Mainmast	= 0·4167	of the whole area	= 1
" " " " Foremast	= 0·2946	" "	
" " " " Mizenmast	= 0·1275	" "	
" the " " Driver	= 0·0808	" "	
" " " " Jib	= 0·0804	" "	

The powers of these sails are for the Main area	1
" " " " Fore area	3
" " " " Mizen area	4
" " " " Driver ...	5
" " " " Jib	5·56

And the moments are from the middle of water-line—

Driver.	*Mizen.*	*Main.*	*Fore.*	*Jib.*
1·94	3·06	10	7·071	1·929
×	×	×	×	×
5	4	1	3	5·56
=	=	=	=	=
9·70	12·24	10	21·213	10·727
		12·24	10·727	
		9·70		

After-moments 31·94 = 31·940 Fore-moments

The area of the Maincourse is	= 0·162	of the whole area	= 1
" " Maintop-sail	= 0·1491	" "	
" " Maintop-gallant sail	= 0·1055	" "	
" " Fore-course	= 0·1146	" "	
" " Foretop-sail	= 0·1055	" "	
" " Foretop-gallant sail	= 0·0746	" "	
" " Mizentop-sail	= 0·0746	" "	
" " Mizentop-gallant sail	= 0·0527	" "	
" " Driver	= 0·081	" "	
" " Jib	= 0·0804	" "	

BALANCE OF SAIL.

I.—CONTINUED.

PLACE OF THE MASTS.

The length of the ship on the load water-line from back of stern-post to front of stem is divided into ten equal parts.

The Mizenmast is placed at one-tenth from the stern-post.
„ Mainmast „ four-tenths „ „
„ Foremast „ eight-tenths „ „

COEFFICIENTS OF PROPORTIONS OF SPARS AND SAILS.

With four yards on each Mast the Course is	= 0·33	of the total sail area on that Mast	The area of the course being given, the length of the yard is equal to $\sqrt{2 \times 0{\cdot}1375 \times A} = \sqrt{0{\cdot}2750 \times \text{area of ship's sails}}$.
„ „ „ „ Topsail	= 0·3035	„ „ „ „	
„ „ „ „ Top-gallant sail	= 0·2147	„ „ „ „	
„ „ „ „ Royal	= 0·1518	„ „ „ „	
With three yards on each Mast the Course is	= 0·3889	„ „ „ „	
„ „ „ „ Topsail	= 0·3579	„ „ „ „	
„ „ „ „ Top-gallant sail	= 0·2532	„ „ „ „	

CLASSIFICATION OF SPARS AND SAILS.

FOR SHIPS WITH FOUR YARDS ON EACH MAST.							FOR SHIPS WITH THREE YARDS ON EACH MAST.						
Classes.	Yards.	Courses.	Diminished Sails.	Drivers.	Jibs.	Ship's Sail Area.	Classes.	Yards.	Courses.	Diminished Sails.	Drivers.	Jibs.	Ship's Sail Area.
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			

„ „ „ „ Topsail = 0·[illegible]35 „ „ „ „
„ „ „ „ Top-gallant sail = 0·2147 „ „ „ „
„ „ „ „ Royal = 0·1518 „ „ „ „
With three yards on each Mast the Course is = 0·3889 „ „ „ „
„ „ „ „ Topsail = 0·3579 „ „ „ „
„ „ „ „ Top-gallant sail = 0·2532 „ „ „ „

The area of the course being given, the length of the yard is equal to $\sqrt{2 \times 0{\cdot}1375 \times A} = \sqrt{0{\cdot}2750 \times \text{area of ship's sails}}$.

CLASSIFICATION OF SPARS AND SAILS.

FOR SHIPS WITH FOUR YARDS ON EACH MAST.

Classes.	Yards.	Courses.	Diminished Sails.	Drivers.	Jibs.	Ship's Sail Area.
12	200·000	20000·00	18408·80	10000·00	11690·91	145454·54
11	168·180	14142·14	13016·99	7071·07	8266·72	102851·90
10	141·421	10000·00	9204·40	5000·00	5845·45	72727·27
9	118·921	7071·07	6508·50	3535·53	4133·36	51425·95
8	100·000	5000·00	4602·20	2500·00	2922·73	36363·63
7	84·089	3535·53	3254·25	1767·77	2066·68	25712·98
6	70·711	2500·00	2301·10	1250·00	1461·36	18181·82
5	59·461	1767·77	1627·12	883·88	1033·34	12856·49
4	50·000	1250·00	1150·55	625·00	730·68	9090·91
3	42·045	883·88	813·66	441·94	516·67	6428·24
2	35·355	625·00	575·28	312·50	365·34	4545·45
1	29·730	441·94	406·83	220·97	258·34	3214·12
	25·000	312·50	287·64	156·25	182·67	2272·73
	21·023	220·97	203·42	110·48	129·17	1607·06
	17·678	156·25	143·82	78·13	91·34	1136·36
	14·865	110·48	101·71	55·24	64·58	803·53
	12·500	78·13	71·91	39·06	45·67	568·18
	10·511	55·24	50·85	27·62	32·29	401·76
	8·839	39·06	35·95	19·53	22·88	284·09
	7·433	27·62	25·43	13·81	16·14	200·88
	6·250	19·53	17·98	9·76	11·44	142·05

FOR SHIPS WITH THREE YARDS ON EACH MAST.

Classes.	Yards.	Courses.	Diminished Sails.	Drivers.	Jibs.	Ship's Sail Area.
12	216·87	23515·16	21644·29	11757·58	11690·91	145454·54
11	182·36	16627·72	15304·82	8313·86	8266·72	102851·90
10	153·35	11757·58	10822·15	5878·79	5845·45	72727·27
9	128·95	8313·86	7652·41	4156·93	4133·36	51425·95
8	108·44	5878·79	5411·07	2939·40	2922·73	36363·63
7	91·18	4156·93	3826·20	2078·47	2066·68	25712·98
6	76·67	2939·40	2705·54	1469·70	1461·36	18181·82
5	64·48	2078·47	1913·10	1039·23	1033·34	12856·49
4	54·22	1469·70	1352·77	734·85	730·68	9090·91
3	45·59	1039·23	956·55	519·62	516·67	6428·24
2	38·34	734·85	676·39	367·42	365·34	4545·45
1	32·24	519·62	478·27	259·81	258·34	3214·12
	27·11	367·42	338·19	183·71	182·67	2272·73
	22·80	259·81	239·14	129·90	129·17	1607·06
	19·17	183·71	169·20	91·86	91·34	1136·36
	16·12	129·90	119·57	64·95	64·58	803·53
	13·56	91·86	84·60	45·93	45·67	568·18
	11·40	64·95	59·79	32·47	32·29	401·76
	9·58	45·93	42·30	22·97	22·88	284·09
	8·06	32·47	29·90	16·23	16·14	200·88
	6·78	22·97	21·15	11·48	11·44	142·05

The coefficient of reduction of Sails = 0·7071
„ „ „ Yards = 0·8409
„ „ „ from Courses to Topsails = 0·92044

BALANCE OF SAIL.

II.

FOUR SQUARE SAILS ON EACH MAST AND JIB TO BALANCE.

1°

	Mizen.		*Main.*		*Fore.*		*Jib.*
Areas	$\frac{5}{24}$	......	$\frac{10}{24}$	......	$\frac{7·071}{24}$	......	$\frac{1·929}{24}$
	×		×		×		×
Leverage	4	......	1	......	3	......	4·5552
	=		=		=		=
Horizontal moments . .	20	......	10	......	21·213	......	8·7869
			20		8·7869		
		After-moments	30	=	29·9999	Fore-moments	

or the centre of effort falls exactly in the middle of the load water-line.

	Mizen.		*Main.*		*Fore.*		*Jib.*
Areas	$\frac{5}{24}$	......	$\frac{10}{24}$	......	$\frac{7·071}{24}$	......	$\frac{1·929}{24}$
	×		×		×		×
Leverage	1·14 a	......	1·6168 a	......	1·332	......	0·8409 a
	=		=		=		=
Vertical moments	5·7 a	......	16·168 a	......	10·418 a	......	1·622 a
			10·418 a				
			1·622 a				
			5·7 a				
			33·908 a	equal to the sum of moments.			

The sum of moments divided by the total area, or 24, gives 1·412 a.

FULL RIG.

2°

	Driver.		*Mizen.*		*Main.*		*Fore.*		*Jib.*
Areas	$\frac{1·65}{24}$	......	$\frac{3·35}{24}$	......	$\frac{10}{24}$	......	$\frac{7·071}{24}$	......	$\frac{1·929}{24}$
	×		×		×		×		×
Leverage	5	......	4	......	1	......	3	......	5·41
	=		=		=		=		=
Horizontal moments . .	8·25	......	13·40	......	10	......	21·213	......	10·436
					13·40		10·436		
					8·25				

33·908 a equal to the sum of moments.

The sum of moments divided by the total area, or 24, gives 1·412 a.

FULL RIG.

2°

	Driver.	Mizen.	Main.	Fore.	Jib.
Areas	$\frac{1·65}{24}$	$\frac{3·35}{24}$	$\frac{10}{24}$	$\frac{7·071}{24}$	$\frac{1·929}{24}$
	×	×	×	×	×
Leverage	5	4	1	3	5·41
	=	=	=	=	=
Horizontal moments ..	8·25	13·40	10	21·213	10·436
			13·40	10·436	
			8·25		

After-moments 31·65 = 31·649 Fore-moments

or ⊙ of effort falls in the middle of load water-line.

	Driver.	Mizen.	Main.	Fore.	Jib.
Areas	$\frac{1·65}{24}$	$\frac{3·35}{24}$	$\frac{10}{24}$	$\frac{7·071}{24}$	$\frac{1·929}{24}$
	×	×	×	×	×
Leverage	0·3535 a	1·5386	1·6168 × a	1·332 × a	0·8409 × a
	=	=	=	=	=
Vertical moments	0·5833 a	5·1543 a	16·168 × a	10·418 a	1·622 a

Sum of vertical moments = 33·9 × a. This, divided by 24, or the whole area, gives for the distance of ⊙ above bottom of sail 1·41 × a.

WITHOUT ROYALS.

3°

	Driver.	Mizen.	Main.	Fore.	Jib.
Areas	$\frac{1·65}{24}$	$\frac{2·591}{24}$	$\frac{8·482}{24}$	$\frac{5·998}{24}$	$\frac{1·682}{24}$
	×	×	×	×	×
Leverage	5	4	1	3	5·41
	=	=	=	=	=
Horizontal moments ..	8·25	10·364	8·482	17·994	9·099
			10·364	9·099	
			8·25		

After-moments 27·096 = 27·093 Fore-moments

or ⊙ of effort falls in the middle of load water-line.

	Driver.	Mizen.	Main.	Fore.	Jib.
Areas	$\frac{1·65}{24}$	$\frac{2·591}{24}$	$\frac{8·482}{24}$	$\frac{5·998}{24}$	$\frac{1·682}{24}$
	×	×	×	×	×
Leverages	0·3535 × a	1·33 × a	1·33 × a	1·25	0·8409 × a
	=	=	=	=	=
Vertical moments	0·5833 × a	3·444 × a	11·328 × a	7·548 × a	1·414

Sum of the vertical moments = 24·317. This, divided by 20·40, or the area, gives for the distance of ⊙ above bottom of sail 1·21 × a.

BALANCE OF SAIL.

II.—CONTINUED.

WITHOUT ROYALS AND TOP-GALLANT SAILS.

4°

	Driver.	*Mizen.*	*Main.*	*Fore.*	*Jib.*
Areas	$\frac{1·65}{24}$	$\frac{1·518}{24}$	$\frac{6·335}{24}$	$\frac{4·48}{24}$	$\frac{1·334}{24}$
	×	×	×	×	×
Leverages	5	4	1	3	5·41
	=	=	=	=	=
Horizontal moments	8·25	6·072	6·335	13·44	7·216
			6·072	7·216	
			8·25		

After-moments 20·657 = 20·656 Fore-moments

or ⊙ of effort falls in the middle of load water-line.

	Driver.	*Mizen.*	*Main.*	*Fore.*	*Jib.*
Areas	$\frac{1·65}{24}$	$\frac{1·518}{24}$	$\frac{6·355}{24}$	$\frac{4·48}{24}$	$\frac{1·334}{24}$
	×	×	×	×	×
Leverages	$0·3535 \times a$	$1·1919 \times a$	$0·97 \times a$	$0·85 \times a$	$0·8409 \times a$
	=	=	=	=	=
Vertical moments	0·5833	1·41	6·16	3·82	1·12

Sum of vertical moments = $13·0933 \times a$. This, divided by 15·32, or the area, gives for the distance of ⊙ above bottom of sail $0·85 \times a$.

UNDER TOPSAILS ONLY.

5°

	Mizentop-sail.	*Maintop-sail.*	*Foretop-sail.*	*Storm-Jib.*
Areas	$\frac{1·518}{24}$	$\frac{3·035}{24}$	$\frac{2·147}{24}$	$\frac{0·4927}{24}$
	×	×	×	×
Leverage	4	1	3	5·41
	=	=	=	=
Horizontal moments	6·072	3·035	6·441	2·66
		6·072	2·66	

After-moments 9·10 = 9·10 Fore-moments

or ⊙ of effort falls in the middle of load water-line.

	Mizen.	*Main.*	*Fore.*	*Jib.*

Sum of vertical moments = 13·0933 × a. This, divided by 15·32, or the area, gives for the distance of ⊙ above bottom of sail 0·85 × a.

UNDER TOPSAILS ONLY.

5°

	Mizentop-sail.		Maintop-sail.		Foretop-sail.		Storm-Jib.
Areas	$\frac{1·518}{24}$	......	$\frac{3·035}{24}$	......	$\frac{2·147}{24}$	......	$\frac{0·4927}{24}$
	×		×		×		×
Leverage	4	......	1	......	3	......	5·41
	=		=		=		=
Horizontal moments ..	6·072	......	3·035	......	6·441	......	2·66
			6·072		2·66		

After-moments 9·10 = 9·10 Fore-moments

or ⊙ of effort falls in the middle of load water-line.

	Mizen.		Main.		Fore.		Jib.
Areas	$\frac{1·518}{24}$	......	$\frac{3·035}{24}$	......	$\frac{2·147}{24}$	......	$\frac{0·4927}{24}$
	×		×		×		×
Leverage	1·1919 × a	......	1·4848 × a	......	1·3257 × a	......	0·8409
	=		=		=		=
Moments	1·81	......	4·51	......	2·85	......	0·41

Sum of vertical moments = 9·58 × a. This, divided by 7·19, or the area, gives for the distance of ⊙ above bottom of sail 1·33 × a.

UNDER COURSES AND DRIVER ONLY.

6°

	Driver.		Maincourse.		Forecourse.		Jib.
Areas	$\frac{1·65}{24}$	......	$\frac{3·3}{24}$	......	$\frac{2·3333}{24}$	......	$\frac{0·843}{24}$
	×		×		×		×
Leverage	5	......	1	......	3	......	5·41
	=		=		=		=
Horizontal moments ..	8·25	......	3·3	......	6·9999	......	4·56
			8·25		4·56		

After-moments 11·55 = 11·55 Fore-moments

or ⊙ falls in the middle of load water-line.

	Driver.		Maincourse.		Forecourse.		Jib.
Areas	$\frac{1·65}{24}$	......	$\frac{3·3}{24}$	......	$\frac{2·3333}{24}$	......	$\frac{0·843}{24}$
	×		×		×		×
Leverage	0·3535 × a	......	0·5 × a	......	0·42 × a	......	0·8409 × a
	=		=		=		=
Moments	0·58 × a	......	1·65 × a	......	0·979	......	0·708

Sum of vertical moments = 3·917 × a. This, divided by 8·126, or the area, gives for the distance of ⊙ of effort from bottom of sail 0·48 × a.

BALANCE OF SAIL.

II.—CONCLUDED.

UNDER TOP-GALLANT SAILS ONLY.

7°

	Mizentop-gallant sail.	*Maintop-gallant sail.*	*Foretop-gallant sail.*	*Jib.*
Areas	$\frac{1·073}{24}$ ×	$\frac{2·147}{24}$ ×	$\frac{1·518}{24}$ ×	$\frac{0·348}{24}$ ×
Leverage	4 =	1 =	3 =	5·41 =
Moments	4·292	2·147	4·554	1·885
		4·292	1·885	
		After-moments 6·439 =	6·439 Fore-moments.	

or ⊙ of effort falls in centre of load water-line.

	Mizentop-gallant sail.	*Maintop-gallant sail.*	*Foretop-gallant sail.*	*Jib.*
Areas	$\frac{1·073}{24}$ ×	$\frac{2·147}{24}$ ×	$\frac{1·518}{24}$ ×	$\frac{0·348}{24}$ ×
Leverage	$1·7025 \times a$ =	$2·4076 \times a$ =	$2·0246 \times a$ =	$0·8409 \times a$ =
Moments	$1·8267 \times a$	$5·169 \times a$	$3·07 \times a$	$2·926 \times a$

Sum of vertical moments = 10·3583. This divided by 5·086, or the area, gives for the distance of ⊙ of effort from bottom of sail $2·05 \times a$.

UNDER ROYALS ONLY.

8°

	Mizen-royal sail.	*Main-royal sail.*	*Fore-royal sail.*	*Jib.*
Areas	$\frac{0·759}{24}$ ×	$\frac{1·518}{24}$ ×	$\frac{1·073}{24}$ ×	$\frac{0·347}{24}$ ×
Leverage	4 =	1 =	3 =	5·41 =
Moments	3·036	1·518	[illegible]	[illegible]

… or the area, gives for the distance of ⊙ of effort from bottom of sail $2{\cdot}05 \times a$.

UNDER ROYALS ONLY.

8°

	Mizen-royal sail.	*Main-royal sail.*	*Fore-royal sail.*	*Jib.*
Areas	$\frac{0{\cdot}759}{24}$	$\frac{1{\cdot}518}{24}$	$\frac{1{\cdot}073}{24}$	$\frac{0{\cdot}247}{24}$
	×	×	×	×
Leverage	4	1	3	5·41
	=	=	=	=
Moments	3·036	1·518	3·219	1·34
		3·036	1·34	
	After-moments	4·554 =	4·559	Fore-moments

or ⊙ of effort falls in the middle of load water-line.

	Mizen-royal sail.	*Main-royal sail.*	*Fore-royal sail.*	*Jib.*
Areas	$\frac{0{\cdot}759}{24}$	$\frac{1{\cdot}518}{24}$	$\frac{1{\cdot}073}{24}$	$\frac{0{\cdot}247}{24}$
	×	×	×	×
Leverage	$2{\cdot}25 \times a$	$3{\cdot}1837 \times a$	$2{\cdot}677 \times a$	$0{\cdot}8409 \times a$
	=	=	=	=
Vertical moments	$1{\cdot}71 \times a$	$4{\cdot}84 \times a$	$2{\cdot}87 \times a$	0·207

Sum of vertical moments $= 9{\cdot}627 \times a$. This, divided by 3·597, or the area, gives for the distance of ⊙ of effort from bottom of sail $2{\cdot}67 \times a$.

NOTE.

In the above calculations, a is the height of the maincourse;

Of a single topsail the ⊙ of effort lies at $\frac{16}{33}$ from its base;

Of the three topsails, viz. topsail, topgallant sail, and royal, the ⊙ of effort is situated at $\frac{6}{13}$ from the bottom of the lowest sail; and

Of all the four sails on one mast the ⊙ of effort is situated at $\frac{5}{11}$ from the bottom of the course.

DIMENSIONS AND AREAS OF SAILS FOR A GIVEN SAIL AREA.

Ship's Sail Area.	Main Yards.	Maintop-sail and Fore-Lower Yard.	Maintop-gallant Foretop-sail and Cross-jack.	Main-Royal Foretop-gallant and Mizentop-sail Yard.	Fore-Royal and Mizentop-gallant Yard.	Mizen-Royal Yard.	Area of Main-courses.	Area of Fore-courses.	Area of Maintop-sail.	Area of Maintop-gallant and Foretop-sail.	Area of Main-Royal Foretop-gallant and Mizentop-sail.	Area of Fore-Royal and Mizentop-gallant Sail.	Area of Mizen-Royal Sail.	Area of Jib.	Area of Drivers.
145455	200	168·18	141·42	118·92	100·0	84·09	20000	14138	18409	13018	9205	6504	4610	11694	10000
144004	199	167·34	140·71	118·33	99·5	83·67	19801	13997	18224	12888	9113	6437	4565	11578	9900
142560	198	166·50	140·01	117·74	99·0	83·25	19602	13857	18042	12757	9020	6372	4519	11462	9801
141124	197	165·66	139·30	117·14	98·5	82·83	19405	13717	17860	12629	8930	6303	4472	11345	9702
139695	196	164·82	138·59	116·55	98·0	82·41	19208	13579	17679	12501	8839	6243	4427	11230	9604
138273	195	163·98	137·89	115·95	97·5	81·99	19013	13439	17499	12373	8749	6180	4383	11117	9506
136858	194	163·13	137·18	115·36	97·0	81·57	18818	13303	17321	12248	8660	6117	4338	11004	9409
135451	193	162·29	136·47	114·76	96·5	81·15	18625	13165	17142	12121	8570	6054	4293	10890	9312
134051	192	161·45	135·77	114·17	96·0	80·73	18432	13029	16965	11995	8482	5993	4249	10778	9216
132658	191	160·61	135·06	113·57	95·5	80·31	18241	12894	16789	11873	9394	5929	4205	10666	9120
131273	190	159·77	134·35	112·97	95·0	79·89	18050	12760	16614	11748	8307	5874	4153	10551	9025
129895	189	158·93	133·64	112·38	94·5	79·46	17861	12625	16440	11625	8222	5813	4110	10442	8931
128524	188	158·09	132·94	111·78	94·0	79·05	17672	12491	16267	11502	8131	5751	4066	10331	8836
127160	187	157·25	132·23	110·19	93·5	78·63	17485	12357	16094	11378	8047	5689	4022	10120	8743
125704	186	156·41	131·52	109·59	93·0	78·21	17298	12226	15922	11257	7961	5629	3979	10112	8648
124455	185	155·57	130·81	109·99	92·5	77·79	17113	12095	15751	11138	7876	5569	3937	10003	8557
123113	184	154·73	130·11	109·40	92·0	77·37	16928	11966	15581	11018	7792	5509	3896	9898	8464
121778	183	153·89	129·40	108·81	91·5	76·95	16745	11837	15412	10900	7707	5450	3853	9790	8373
120451	182	153·05	128·69	108·21	91·0	76·53	16562	11708	15244	10783	7622	5391	3811	9684	8281
119131	181	152·21	127·99	107·62	90·5	76·11	16381	11580	15077	10668	7544	5334	3771	9575	8191
117818	180	151·36	127·28	107·03	90·0	75·68	16200	11452	14911	10549	7459	5275	3730	9470	8100
116513	179	150·52	126·57	106·43	89·5	75·26	16021	11325	14746	10434	7375	5217	3689	9367	8011
115215	178	149·68	125·86	105·84	89·0	74·84	15842	11199	14582	10318	7290	5159	3647	9262	7921
113924	177	148·84	125·16	105·24	88·5	74·42	15665	11073	14419	10205	7219	5103	3608	9158	7833
112640	176	148·00	124·45	104·65	88·0	74·00	15488	10947	14257	10079	7127	5039	3562	9054	7744
111364	175	147·16	123·74	104·05	87·5	73·58	15313	10823	14095	9965	7046	4988	3527	8951	7657
110095	174	146·32	123·04	103·46	87·0	73·16	15138	10701	13934	9853	6966	4927	3485	8850	7569
108833	173	145·48	122·33	102·86	86·5	72·74	14965	10578	13774	9740	6886	4870	3443	8750	7483

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
111364	175	147·16	123·74	104·05	87·[illegible]	73·58	15313	10823	14095	[illegible]65	7046	4988	3527	8951	7657
110095	174	146·32	123·04	103·46	87·0	73·16	15138	10701	13934	9853	6966	4927	3485	8850	7569
108833	173	145·48	122·33	102·86	86·5	72·74	14965	10578	13774	9740	6886	4870	3443	8750	7483
107578	172	144·64	121·62	102·27	86·0	72·34	14792	10457	13615	9628	6807	4814	3404	8650	7396
106331	171	143·80	120·92	101·67	85·5	71·90	14621	10335	13457	9517	6729	4759	3364	8549	7311
105091	170	142·95	120·21	101·08	85·0	71·48	14450	10215	13300	9406	6651	4703	3325	8449	7225
103858	169	142·11	119·50	100·49	84·5	71·06	14281	10095	13144	9296	6572	4648	3287	8350	7141
102633	168	141·27	118·79	99·89	84·0	70·64	14112	9976	12989	9185	6494	4593	3247	8251	7056
101415	167	140·43	118·09	99·30	83·5	70·22	13945	9857	12835	9076	6417	4539	3209	8153	6973
100204	166	139·59	117·38	98·70	83·0	69·79	13778	9740	12682	8968	6341	4489	3173	8056	6889
99000	165	138·75	116·67	98·11	82·5	69·38	13613	9623	12530	8861	6265	4431	3133	7960	6806
97804	164	137·91	115·97	97·51	82·0	68·96	13448	9507	12379	8754	6189	4377	3095	7865	6724
96615	163	137·07	115·26	96·92	81·5	68·54	13285	9391	12229	8647	6114	4324	3058	7771	6643
95433	162	136·23	114·55	96·32	81·0	68·12	13112	9276	12079	8542	6039	4271	3020	7678	6556
94258	161	135·39	113·84	95·73	80·5	67·70	12961	9162	11930	8438	5966	4219	2983	7579	6481
93091	160	134·54	113·14	95·14	80·0	67·27	12800	9048	11782	8332	5890	4166	2945	7484	6400
91931	159	133·70	112·43	94·54	79·5	66·85	12641	8935	11634	8229	5818	4115	2910	7391	6321
90778	158	132·86	111·71	93·95	79·0	66·43	12482	8823	11488	8127	5746	4064	2873	7298	6241
89633	157	132·02	111·01	93·35	78·5	66·01	12325	8712	11343	8022	5671	4011	2836	7206	6163
88495	156	131·18	110·30	92·76	78·0	65·59	12168	8601	11199	7920	5599	3960	2800	7114	6084
87364	155	130·34	109·59	92·16	77·5	65·17	12013	8492	11056	7819	5528	3909	2763	7024	6007
86240	154	129·50	108·88	91·57	77·0	64·75	11858	8383	10914	7718	5457	3859	2728	6934	5929
85124	153	128·66	108·18	90·97	76·5	64·33	11705	8274	10773	7618	5386	3809	2693	6844	5853
84015	152	127·82	107·47	90·38	76·0	63·91	11552	8166	10633	7519	5316	3759	2657	6755	5776
82913	151	126·98	106·76	89·78	75·5	63·49	11401	8059	10494	7420	5246	3710	2623	6666	5701
81818	150	126·14	106·06	89·19	75·0	63·07	11250	7953	10355	7323	5177	3662	2589	6579	5625
80731	149	125·30	105·36	88·60	74·5	62·65	11101	7847	10217	7225	5109	3613	2554	6490	5551
79651	148	124·46	104·65	88·00	74·0	62·23	10952	7742	10080	7128	5040	3564	2520	6404	5476
78578	147	123·62	103·94	87·41	73·5	61·81	10805	7638	9944	7032	4971	3516	2485	6317	5403
77513	146	122·78	103·24	86.81	73·0	61·39	10658	7534	9809	6937	4905	3469	2452	6232	5329
76455	145	121·94	102·53	86·22	72·5	60·97	10513	7431	9675	6842	4837	3421	2419	6147	5257
75404	144	121·10	101·82	86·62	72·0	60·55	10368	7328	9542	6748	4771	3374	2386	6062	5184
74360	143	120·26	101·12	85·03	71·5	60·13	10225	7227	9410	6655	4706	3328	2353	5979	5113
73324	142	119·42	100·41	84·43	71·0	59·71	10082	7126	9279	6562	4639	3281	2321	5895	5041
72295	141	118·58	99·70	83·84	70·5	59·29	9941	7028	9149	6470	4574	3235	2288	5813	4971
71273	140	117·73	98·99	83·24	70·0	58·87	9800	6926	9020	6379	4510	3189	2254	5731	4900

DIMENSIONS AND AREAS OF SAILS FOR A GIVEN SAIL AREA.

[CONTINUED.]

Ship's Sail Area.	Main Yards.	Maintop-sail and Fore-Lower Yard.	Maintop-gallant Foretop-sail and Cross-jack.	Main-Royal Foretop-gallant and Mizentop-sail Yard.	Fore-Royal and Mizentop-gallant Yard.	Mizen-Royal Yard.	Area of Main-courses.	Area of Fore-courses.	Area of Maintop-sail.	Area of Maintop-gallant and Foretop-sail.	Area of Main-Royal Foretop-gallant and Mizentop-sail.	Area of Fore-Royal and Mizentop-gallant Sail.	Area of Mizen-Royal Sail.	Area of Jib.	Area of Drivers.
70258	139	116·89	98·29	82·65	69·5	58·45	9661	6829	8893	6288	4446	3144	2223	5649	4831
69251	138	116·05	97·58	82·05	69·0	58·03	9522	6721	8766	6198	4382	3099	2191	5568	4761
68251	137	115·21	96·87	81·46	68·5	57·61	9385	6634	8639	6108	4319	3054	2159	5487	4693
67258	136	114·37	96·17	80·86	68·0	57·19	9248	6538	8513	6020	4256	3010	2128	5407	4624
66273	135	113·53	95·46	80·27	67·5	56·77	9113	6442	8388	5932	4194	2966	2097	5329	4557
65295	134	112·69	94·74	79·67	67·0	56·35	8978	6346	8264	5844	4132	2922	2065	5249	4489
64324	133	111·85	94·04	79·08	66·5	55·93	8845	6252	8141	5757	4070	2879	2035	5172	4423
63360	132	111·01	93·33	78·48	66·0	55·56	8712	6159	8019	5671	4010	2836	2005	5094	4356
62404	131	110·17	92·62	77·89	65·5	55·59	8581	6066	7898	5585	3949	2793	1975	5017	4291
61455	130	109·32	91·92	77·30	65·0	54·66	8450	5974	7778	5500	3889	2750	1944	4941	4225
60513	129	108·48	91·22	76·70	64·5	54·24	8321	5882	7658	5416	3829	2708	1915	4865	4161
59578	128	107·64	90·51	76·11	64·0	53·82	8192	5792	7540	5333	3770	2667	1886	4790	4096
58651	127	106·80	89·80	75·51	63·5	53·40	8065	5701	7423	5249	3711	2624	1855	4715	4033
57731	126	105·96	89·10	74·92	63·0	52·98	7938	5612	7307	5166	3652	2583	1826	4641	3969
56818	125	105·12	88·39	74·32	62·5	52·56	7813	5524	7192	5084	3595	2542	1797	4569	3907
55913	124	104·28	87·68	73·73	62·0	52·14	7688	5436	7077	5003	3537	2501	1769	4495	3844
55015	123	103·44	86·97	73·13	61·5	51·72	7565	5348	6963	4922	3479	2461	1740	4423	3783
54124	122	102·60	86·26	72·54	61·0	51·30	7442	5244	6850	4842	3423	2421	1712	4352	3721
53240	121	101·76	85·56	71·94	60·5	50·88	7321	5175	6738	4763	3367	2382	1684	4280	3661
52364	120	100·91	84·85	71·35	60·0	50·46	7200	5090	6627	4686	3313	2343	1656	4210	3600
51495	119	100·07	84·15	70·76	59·5	50·04	7081	5005	6518	4609	3258	2305	1630	4140	3541
50633	118	99·23	83·44	70·16	59·0	49·62	6962	4923	6409	4532	3204	2266	1602	4070	3481
49778	117	98·39	82·73	69·57	58·5	49·20	6845	4839	6301	4455	3150	2228	1575	4002	3423
48931	116	97·55	82·02	68·97	58·0	48·78	6728	4757	6194	4379	3096	2189	1547	3934	3364
48091	115	96·71	81·32	68·38	57·5	48·36	6613	4679	6088	4304	3043	2152	1521	3866	3307
47258	114	95·87	80·61	67·78	57·0	47·99	6498	4594	5983	4229	2990	2115	1495	3800	3249
46433	113	95·03	79·90	67·19	56·5	47·57	6385	4512	5879	4156	2938	2078	1470	3733	3193

48091	115	96·71	81·32	68·38	57·5	48·36	6613	4679	6088	4304	3043	2152	1521	3866	3307
47258	114	95·87	80·61	67·78	57·0	47·99	6498	4594	5983	4229	2990	2115	1495	3800	3249
46433	113	95·03	79·90	67·19	56·5	47·57	6385	4512	5879	4156	2938	2078	1470	3733	3193
45615	112	94·19	79·20	66·59	56·0	47·10	6272	4433	5774	4084	2888	2042	1443	3667	3136
44804	111	93·35	78·49	66·00	55·5	46·68	6161	4364	5671	4011	2836	2006	1418	3602	3081
44000	110	92·50	77·78	65·41	55·0	46·25	6050	4277	5569	3938	2785	1969	1392	3538	3025
43204	109	91·66	77·07	64·81	54·5	45·83	5941	4199	5467	3867	2734	1934	1367	3473	2971
42415	108	90·82	76·37	64·22	54·0	45·41	5832	4122	5367	3796	2684	1898	1342	3410	2916
41633	107	89·98	75·66	63·62	53·5	44·99	5725	4046	5268	3726	2634	1863	1317	3347	2863
40858	106	89·14	74·95	63·03	53·0	44·57	5618	3971	5170	3656	2585	1828	1293	3285	2809
40091	105	88·30	74·24	62·43	52·5	44·15	5513	3896	5073	3587	2536	1794	1269	3223	2757
39331	104	87·46	73·54	61·84	52·0	43·73	5408	3823	4977	3519	2488	1759	1243	3162	2704
38578	103	86·62	72·83	61·24	51·5	43·31	5305	3749	4882	3451	2440	1725	1220	3101	2653
37833	102	85·78	72·13	60·65	51·0	42·89	5202	3677	4788	3384	2393	1692	1195	3041	2601
37095	101	84·94	71·42	60·05	50·5	42·47	5101	3605	4695	3318	2346	1659	1173	2982	2551
36364	100	84·09	70·71	59·46	50·0	42·05	5000	3534	4602	3254	2301	1627	1150	2924	2500
35660	99	83·25	70·00	58·87	49·5	41·63	4901	3500	4511	3190	2255	1595	1128	2865	2451
34924	98	82·41	69·30	58·27	49·0	41·21	4802	3430	4420	3126	2210	1563	1105	2808	2401
34215	97	81·57	68·59	57·68	48·5	40·79	4705	3324	4330	3063	2165	1532	1083	2751	2353
33513	96	80·73	67·88	57·08	48·0	40·37	4608	3256	4241	3000	2121	1500	1061	2694	2304
32818	95	79·89	67·18	56·49	47·5	39·95	4513	3190	4153	2938	2078	1469	1038	2639	2257
32131	94	79·05	66·47	55·89	47·0	39·53	4418	3123	4066	2877	2034	1438	1017	2583	2209
31451	93	78·21	65·76	55·30	46·5	39·11	4325	3057	3980	2816	1991	1408	996	2529	2163
30778	92	77·37	65·05	54·70	46·0	38·69	4232	2992	3895	2756	1948	1378	975	2474	2116
30113	91	76·53	64·35	54·11	45·5	38·27	4141	2928	3811	2696	1906	1348	953	2421	2071
29455	90	75·68	63·64	53·51	45·0	37·84	4050	2863	3728	2636	1863	1318	932	2368	2025
28804	89	74·84	62·93	52·92	44·5	37·42	3961	2800	3646	2578	1829	1289	911	2316	1981
28160	88	74·00	62·23	52·32	44·0	37·00	3872	2737	3565	2520	1782	1260	891	2264	1936
27524	87	73·16	61·52	51·73	43·5	36·58	3785	2675	3484	2463	1744	1231	871	2212	1893
26895	86	72·32	60·81	51·13	43·0	36·16	3698	2614	3404	2407	1705	1203	851	2162	1849
26273	85	71·48	60·10	50·54	42·5	35·74	3613	2554	3325	2351	1662	1175	831	2112	1807
25658	84	70·64	59·40	49·94	42·0	35·32	3528	2495	3247	2295	1623	1147	810	2063	1764
25051	83	69·80	58·69	49·35	41·5	34·90	3445	2435	3170	2241	1585	1120	792	2014	1723
24451	82	68·96	57·98	48·75	41·0	35·48	3362	2377	3094	2187	1546	1093	773	1966	1681
23858	81	68·12	57·28	48·16	40·5	34·06	3281	2318	3019	2134	1509	1067	754	1918	1641
23273	80	67·27	56·57	47·57	40·0	33·64	3200	2262	2945	2083	1473	1041	736	1871	1600

DIMENSIONS AND AREAS OF SAILS FOR A GIVEN SAIL AREA.

[CONCLUDED.]

Ship's Sail Area.	Main Yards.	Maintop-sail and Fore-Lower Yard.	Maintop-gallant Foretop-sail and Cross-jack.	Main-Royal Foretop-gallant and Mizentop-sail Yard.	Fore-Royal and Mizentop-gallant Yard.	Mizen-Royal Yard.	Area of Main-courses.	Area of Fore-courses.	Area of Maintop-sail.	Area of Maintop-gallant and Foretop-sail.	Area of Main-Royal Foretop-gallant and Mizentop-sail.	Area of Fore-Royal and Mizentop-gallant Sail.	Area of Mizen-Royal Sail.	Area of Jib.	Area of Drivers.
22695	79	66.43	55.86	46.97	39.5	33.22	3121	2206	2872	2032	1436	1016	718	1824	1561
22124	78	65.59	55.15	46.38	39.0	32.80	3042	2151	2800	1981	1401	990	700	1779	1521
21560	77	64.75	54.45	45.78	38.5	32.38	2965	2096	2729	1931	1366	965	683	1734	1483
21004	76	63.91	53.74	45.19	38.0	31.96	2888	2042	2659	1882	1330	941	666	1688	1444
20455	75	63.07	53.03	44.59	37.5	31.54	2813	1988	2590	1833	1296	917	648	1644	1407
19913	74	62.23	52.33	44.00	37.0	31.12	2738	1936	2521	1785	1263	892	631	1601	1369
19378	73	61.39	51.62	43.40	36.5	30.70	2665	1884	2453	1737	1228	868	614	1558	1333
18851	72	60.55	50.91	42.81	36.0	30.28	2592	1832	2386	1689	1194	844	597	1516	1296
18331	71	59.71	50.21	42.21	35.5	29.86	2521	1782	2320	1642	1160	821	581	1473	1261
17818	70	58.86	49.50	41.62	35.0	29.43	2450	1732	2255	1595	1128	797	564	1433	1225
17313	69	58.02	48.79	41.03	34.5	29.01	2381	1683	2191	1549	1095	774	547	1392	1191
16815	68	57.18	48.08	40.43	34.0	28.59	2312	1635	2128	1504	1064	752	531	1352	1156
16324	67	56.34	47.38	39.84	33.5	28.17	2245	1587	2066	1461	1033	730	516	1313	1123
15840	66	55.50	46.67	39.24	33.0	27.75	2178	1540	2005	1418	1003	709	501	1273	1089
15364	65	54.66	45.96	38.65	32.5	27.33	2113	1493	1945	1375	973	687	486	1235	1057
14895	64	53.82	45.26	38.05	32.0	26.91	2048	1447	1886	1333	942	667	472	1197	1024
14433	63	52.98	44.55	37.46	31.5	26.49	1985	1403	1828	1292	913	646	457	1160	993
13978	62	52.14	43.84	36.86	31.0	26.07	1922	1359	1770	1251	885	625	442	1124	961
13531	61	51.30	43.13	36.27	30.5	25.65	1861	1315	1713	1211	856	606	428	1087	931
13091	60	50.45	42.43	35.68	30.0	25.23	1800	1272	1657	1172	828	586	414	1052	900
12658	59	49.61	41.72	35.08	29.5	24.81	1741	1230	1601	1133	801	567	401	1018	871
12233	58	48.77	41.01	34.49	29.0	24.39	1682	1189	1547	1095	775	547	386	983	841
11815	57	47.93	40.31	33.89	28.5	23.97	1625	1148	1494	1057	747	528	374	950	813
11404	56	47.09	39.60	33.30	28.0	23.05	1568	1108	1442	1021	722	510	361	917	784
11000	55	46.25	38.89	32.70	27.5	23.13	1513	1069	1391	985	697	492	348	884	756
10604	54	45.41	38.18	32.11	27.0	22.71	1458	1030	1341	946	669	473	334	852	729
10215	53	44.57	37.48	31.51	26.5	22.29	1405	992	1292	914	646	457	322	821	702

11404	5[illegible]	47·09	39·[illegible]	33·3[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11000	55	46·25	38·89	32·70	27·5	23·13	1513	1069	1391	[illegible]5	697	492	348	884	756
10604	54	45·41	38·18	32·11	27·0	22·71	1458	1030	1341	946	669	473	334	852	729
10215	53	44·57	37·48	31·51	26·5	22·29	1405	992	1292	914	646	457	322	821	703
9833	52	43·73	36·77	30·92	26·0	21·87	1352	955	1244	880	622	440	311	790	676
9458	51	42·89	36·06	30·32	25·5	21·95	1301	919	1197	847	599	423	299	761	651
9091	50	42·05	35·36	29·73	25·0	21·03	1250	883	1151	814	576	407	288	731	625
8731	49	41·21	34·65	29·14	24·5	20·61	1201	849	1106	782	553	391	277	701	601
8378	48	40·37	33·94	28·54	24·0	20·18	1152	814	1061	750	530	375	266	673	576
8033	47	39·53	33·23	27·95	23·5	19·77	1105	780	1017	719	508	359	255	645	553
7695	46	38·69	32·53	27·35	23·0	19·35	1058	747	974	689	487	345	244	618	529
7363	45	37·85	31·82	26·76	22·5	18·93	1013	715	932	659	466	329	233	592	507
7040	44	37·01	31·11	26·16	22·0	18·51	968	684	891	630	445	315	223	566	484
6724	43	36·17	30·41	25·57	21·5	18·09	925	654	851	601	425	301	213	541	463
6415	42	35·33	29·70	24·97	21·0	17·67	882	625	812	574	406	287	203	516	441
6113	41	34·49	28·99	24·38	20·5	17·24	841	594	774	547	387	278	194	491	421
5818	40	33·64	28·28	23·78	20·0	16·82	800	566	736	521	369	260	184	468	400
5531	39	32·80	27·58	23·19	19·5	16·40	761	537	700	495	350	247	175	445	381
5251	38	31·96	26·87	22·59	19·0	15·98	722	510	665	470	332	235	167	422	361
4978	37	31·12	26·16	22·00	18·5	15·56	685	484	631	446	315	223	158	400	343
4713	36	30·28	25·46	21·41	18·0	15·14	648	458	597	422	298	211	149	379	324
4455	35	29·44	24·75	20·81	17·5	14·72	613	432	564	397	281	198	140	358	307
4204	34	28·60	24·04	20·22	17·0	14·30	578	408	532	376	266	188	133	338	289
3960	33	27·76	23·34	19·62	16·5	13·88	545	385	501	354	250	177	125	319	273
3724	32	26·92	22·63	19·03	16·0	13·46	512	362	471	333	235	166	117	300	256
3495	31	26·08	21·92	18·43	15·5	13·04	481	339	442	312	220	156	110	281	241
3273	30	25·23	21·21	17·84	15·0	12·67	450	318	414	293	206	146	103	263	225
3058	29	24·39	20·51	17·24	14·5	12·20	421	297	387	274	193	137	97	246	211
2851	28	23·55	19·80	16·65	14·0	11·78	392	277	361	255	181	127	90	229	196
2651	27	22·71	19·09	16·05	13·5	11·36	365	258	335	238	169	119	84	213	183
2458	26	21·87	18·39	15·46	13·0	10·94	338	239	311	220	156	110	78	198	169
2273	25	21·03	17·68	14·86	12·5	10·52	313	221	287	203	143	101	72	183	157
2095	24	20·19	16·97	14·27	12·0	10·09	288	203	264	187	132	93	66	168	144
1924	23	19·35	16·26	13·67	11·5	9·68	265	187	243	172	121	86	61	155	133
1760	22	18·51	15·56	13·08	11·0	9·26	242	171	223	158	112	79	56	142	121
1604	21	17·67	14·85	12·48	10·5	8·84	221	156	203	143	101	71	50	129	111
1455	20	16·82	14·14	11·89	10·0	8·41	200	141	184	129	91	64	45	117	100

CHAPTER XV.

ON THE PROPORTION, BALANCE, DIVISION, AND DISTRIBUTION OF SAILS.

Proportion of sail to midship section usually 36 : 1.

A good fast frigate in a ten-knot breeze can carry 36 square feet of sail for each square foot of area of midship section, and be the better for it; if she carried more, she might be pressed over so much, as to be the worse for it, and go slower: hence it has been common to provide a sail-area of one square fathom of canvas, for one square foot of midship section to be driven through the water; this proportion can be considerably exceeded by yachts and despatch vessels, even up to 100 square feet, but such vessels have been called sailing machines rather than ships: nevertheless, for light winds, all vessels carry a great quantity of light sail beyond their proportiou of regular working sail.

Taking sail area in the proportion of a square fathom of sail to a sqnare foot of midship section, is merely saying how much canvas the ship should have, iu order to drive her: whether she will be able to staud up under it, and whether under it she will prove leewardly or weatherly, are other questious—questions of stability and of balance of sail. All ships tend, under a side-wind, to drift the way the wind blows, broadside through the water: the only preventive to this is the extent of the immersed longitudinal section, which offers resistance throughout the whole of the length and depth of the ship in the water. The dimensions and shape of this section determine the arrangement and balance of the sail, and a ship should be sufficiently weatherly to carry an area of fore-aud-aft sail, not less than six times the area of this under-water longitudinal section.

Equivalent sail area;

As a first step to the consideration of the distribution and balauce of sail, I draw this section of the ship under its proper water-line, and I copy it by drawing above it a similar section in the air, only six times as high; this I call *the equivalent sail area,* and it shows, without regard to the kind of ship, the quantity and disposition of sail whicb she may carry: it is, in short, what the sails might be, or would be, if she could conveniently carry tbem all in oue. Indeed a ship with one sail is, perhaps, more effective than with any other number; bnt, the larger the vessel, the more must her sails be subdivided, for convenience of handling. There is also a limit to the size, at which sails can be made strong enough, and stretched flat.

as one sail.

In figure A, I have drawn the equivalent sail, and if the vessel were so small, that she could carry the whole in one sail, she would be what is commouly called “a lugger,” and the sail itself what is commonly

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As a first step to the consideration of the distribution and balance of sail, I draw this section of the ship under its proper water-line, and I copy it by drawing above it a similar section in the air, only six times as high; this I call *the equivalent sail area*, and it shows, without regard to the kind of ship, the quantity and disposition of sail which she may carry: it is, in short, what the sails might be, or would be, if she could conveniently carry them all in one. Indeed a ship with one sail is, perhaps, more effective than with any other number; but, the larger the vessel, the more must her sails be subdivided, for convenience of handling. There is also a limit to the size, at which sails can be made strong enough, and stretched flat. **Equivalent sail area; as one sail.**

In figure A, I have drawn the equivalent sail, and if the vessel were so small, that she could carry the whole in one sail, she would be what is commonly called "a lugger," and the sail itself what is commonly called "a lug sail." It is also to be remarked, that the centre of effort of the wind on this sail will be precisely over the centre of resistance of the longitudinal section in the water, and so there will be a perfect balance of sail.

If the vessel be too long to enable the sail to be carried in one, it may be carried in two, without much alteration of shape, and such a vessel will be the common lugger with two masts, as in figure B. **As two or more sails.**

In like manner the sail may be divided into three, and hung on three masts, as in figure C, and then the vessel will be a three-masted lugger.

Thus it is plain, that this equivalent sail may be obtained indifferently by one, two, or three sails on one, two, or three masts, as a matter of convenience merely; that is, it leaves us perfectly free to make any decision we please as to distribution, provided we maintain the place and size of the sail, and therefore the balance.

In lighter winds it may be desirable to carry additional sail; all that it is necessary to observe is, that

There is a sound argument in favour of diminishing the heads of the sails, that the higher masts and gear are lighter than the lower, and, therefore, less capable of carrying heavy and large sails and yards. On the opposite side there is this argument, that the upper sails are not spread in bad weather, but are taken in when it blows hard; so that, being fair-weather sails, they should be large, or they will be of little use.

In adopting the particular degree of diminution of head of sail, or taper, which is shown in the plates and tables of balance and sail, I have given greater weight than usual to the latter consideration. I have given the upper sails a rather wide spread, and I have given them a smaller proportion of height to width than is common. I observe a growing tendency in fast vessels to carry large and low sails, and to obtain greater spread of sail, with less hoist. I believe also, that, with the adoption of iron as the material for masts and rigging, sails of great spread and moderate hoist will be more and more used.

In considering what diminution of sail you may adopt in any given ship, three things should be kept in mind: 1st. That, by increasing the spread of your lower sails and tapering rapidly the upper, you bring down the centre of effort of the sails. 2nd. That, by narrowing the upper sails, they become of less area and of less value. 3rd. That, in altering the taper, you have only to take care that, by so much as the alteration adds to one part of the sail area on a given mast, by so much also shall it diminish the area at another part. Thus any amount of change or diminution may be given to the sails on each mast, without changing the balance of sail area on the whole ship.

Spread and hoist of a sail.

II. *Proportion of height to width in a given square sail is a matter of choice.*—It seems to me that, in proportion as ships sail faster, and are made finer and longer, the separate sails are made broader and lower, their yards longer, and their hoist less. By giving squareness to a sail, yon not only carry a larger quantity of low sail, but the sails stand flatter and better on a wind. On the contrary, there is this consideration, that yards of great length are costly and heavy—heavy to carry and heavy to work; and that, by merely increasing the hoist, the same yard may be made to carry much more canvas and do much more work.

This goes in favour of increased hoist; bnt it loses weight from this further consideration, that a square sail of great height does not stand well on a wind; and that a fast ship will sail faster on a wind with square and low sails, than with high and narrow ones.

The fact, that yards of great spread are heavy to carry and hard to work, will, therefore, be a sound argument in favour of narrow and higb sails, for slow ships, for short voyages, and for underhanded ships with small crews. On the other band, in long ocean voyages, and with an able crew of seamen, spread being of value, long yards and a moderate hoist are preferable.

The limits of proportion I take to be

Spread and hoist of a sail.

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This goes in favour of increased hoist; but it loses weight from this further consideration, that a square sail of great height does not stand well on a wind; and that a fast ship will sail faster on a wind with square and low sails, than with high and narrow ones.

The fact, that yards of great spread are heavy to carry and hard to work, will, therefore, be a sound argument in favour of narrow and high sails, for slow ships, for short voyages, and for underhanded ships with small crews. On the other hand, in long ocean voyages, and with an able crew of seamen, spread being of value, long yards and a moderate hoist are preferable.

The limits of proportion I take to be these:—When the hoist of a square sail is made equal to its spread, I reckon that to be an extreme height of sail. When the hoist is one-half of the greatest width, I reckon that to be a broad and low sail. I do not like to see them lower, as it seems wasteful, because a sail of that height will stand close to the wind; therefore I have taken that as my standard proportion of height to width.

Subdivision of sails on a mast.

III. *Subdivision of sails on a mast.*—It is plain that the proportion of width to height of sail may be considered apart from taper, or diminution of head: nevertheless, a rapid rate of diminution may better suit high sails, and a slower rate lower sails. But much of the symmetry or ugliness of a ship's suit of sails depends on keeping some one proportion of height to width of sail throughout the sails on the same mast, and throughout the sails on the different masts of the same ship. I observe, that in fast ships there is a strong tendency in this direction: and I believe that the introduction of iron masts, which frees us from the difficulty of finding spars of sufficient length and strength in the forests, and enables us to make masts of any length in one piece, without break or discontinuity, is a great encouragement to the adoption of symmetry and uniformity in the proportion and fashion of sail. It seems plain, that when some one proportion of height to width has been selected, as possessing the requisite qualities in the best practical degree, there can be no sufficient reason for adopting that proportion in one sail on a mast, and rejecting it in the others.

I take, therefore, the sails on one mast, and divide them so that they may all have one proportion of spread and hoist. But that subdivision may be altered in any way, that the sailing-master may find most convenient for working. In English men-of-war the topsail is the grand working sail of the ship: it is generally of great hoist, and may be taken as an extreme proportion. In the double-topsail sailing-clipper the same sail is cut into two sails, often of a ridiculously small hoist. These are two extremes, between which, I believe, there must be some rational medium.

I conclude by repeating, that the subdivision of sails on a mast is a matter of seamanship, rather than naval construction,—is more a question of working, than designing, a ship. Generally speaking, the sails a captain likes best, he will work best. What he likes, will depend not merely on his experience, but on the power at his disposal to work them, and on the value of speed to his ship-owners. Given a stable, fine, fleet ship for long voyages, I should adopt sails not high, but of great spread. For short voyages, narrow seas, moderate speed, and an underhanded ship's company, narrow sails, lofty and easily worked, may be preferred: and in like manner, sails few and large, or many and small, have corresponding advantages or disadvantages.

Fore-and-aft sails.

Hitherto I have referred mainly to sails of a quadrangular shape, carried on square yards. They are not only the most universal form and arrangement, but are universally used on the largest scale. Triangular sails, or trysails, are not less valuable, but are to be reckoned, in some sort, as subsidiary sails. They take their form almost inevitably from other considerations, to which they are subordinate. Thus, even the jib of a man-of-war, the chief trysail, takes its shape and proportion almost exclusively from the angle of the fore-topstay, and is decided in shape by the proportion of masts, and direction of rigging, which have been determined by precedent considerations.

Trysails:

If, however, there be less scope for choice or design in trysails than in square sails, there is this compensating virtue in the triangular form, that it is more versatile and accommodating than the square sail. A trysail of given area will take any shape without losing its value. A jib, covering a given length of bowsprit, is of the same area, provided it rise to a given height, measured square off the line of bowsprit, and does not vary with any angle of skew that may happen to be given to it; and so long as it rises to the same height, its centre of effort will be at the same height, again taken square from the bowsprit. Thus every variety of skew may be given to a trysail of given height and base, to suit convenience in other respects.

lie close to wind.

There is also another point in which a triangular sail differs from a square sail—it draws well, independently of its height. So long as a triangular sail is not too wide fore and aft, it will set flat, close to the wind, and without the large belly which great height would give a square sail. The chief virtue of trysails is this special quality of setting flat, and going close to the wind. I know many sailors who would cover their ships with trysails and staysails, if they could find stays to carry them. The fact of their being attached to a stay on their windward edge, gives them a power of setting flat and close, which no other sails possess.

Boom-sails.

Spankers, or boom sails, have the advantages, like triangular or stay sails, of being fast forward, and so close on a wind, that they must stand well and keep flat. The gaff, or upper boom, which carries them, has the vary with any angle of skew that may happen to be given to it; and so long as it rises to the same height, its centre of effort will be at the same height, again taken square from the bowsprit. Thus every variety of skew may be given to a trysail of given height and base, to suit convenience in other respects.

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Spankers, or boom sails, have the advantages, like triangular or stay sails, of being fast forward, and so close on a wind, that they must stand well and keep flat. The gaff, or upper boom, which carries them, has the disadvantage of tending to sway over to leeward; and the top shakes while the foot of the sail stands. The modern fashion of lacing sails to the boom gives boom-trysails and spankers the power of sitting flat as boards, and going close to the wind.

In calculating the balance and distribution of triangular sails, boom-sails, boom-trysails, spankers, and, in general, of fore-and-aft sails, it may be said to be matter of indifference, what the sort of sail is: you may substitute, at any point you choose, fore-and-aft sails for square sails, provided you keep the same area and preserve the balance-point or centre of effort of the sails in the same place. The sails will balance the ship equally well, whether square or fore-and-aft.

Fore-and-aft sails shift centre of effort as they turn.

But there is this radical difference between fore-and-aft sails and square sails. Fore-and-aft sails shift their centres with their trim. They travel in circles round a fixed point, and they carry their centres of effort round with them. Square sails never shift their centres of effort, so long as they set flat: these centres are fixed points on the masts round which they turn.

This travel or shift of centre of all trysails, triangular sails, spankers, and boom-sails, is of considerable importance, because it carries the centre of effort forward as the course of the ship goes off the wind. It returns towards its place as the ship is closer hauled; but it must be kept in mind that it is always a little forward of its calculated place: and this is, perhaps, one of the reasons why, in fore-and-aft rigged vessels, the centre of effort of the sails requires a smaller shift forward of the middle, in order to meet the shift of the centre of resistance of the body of the ship as the speed increases.

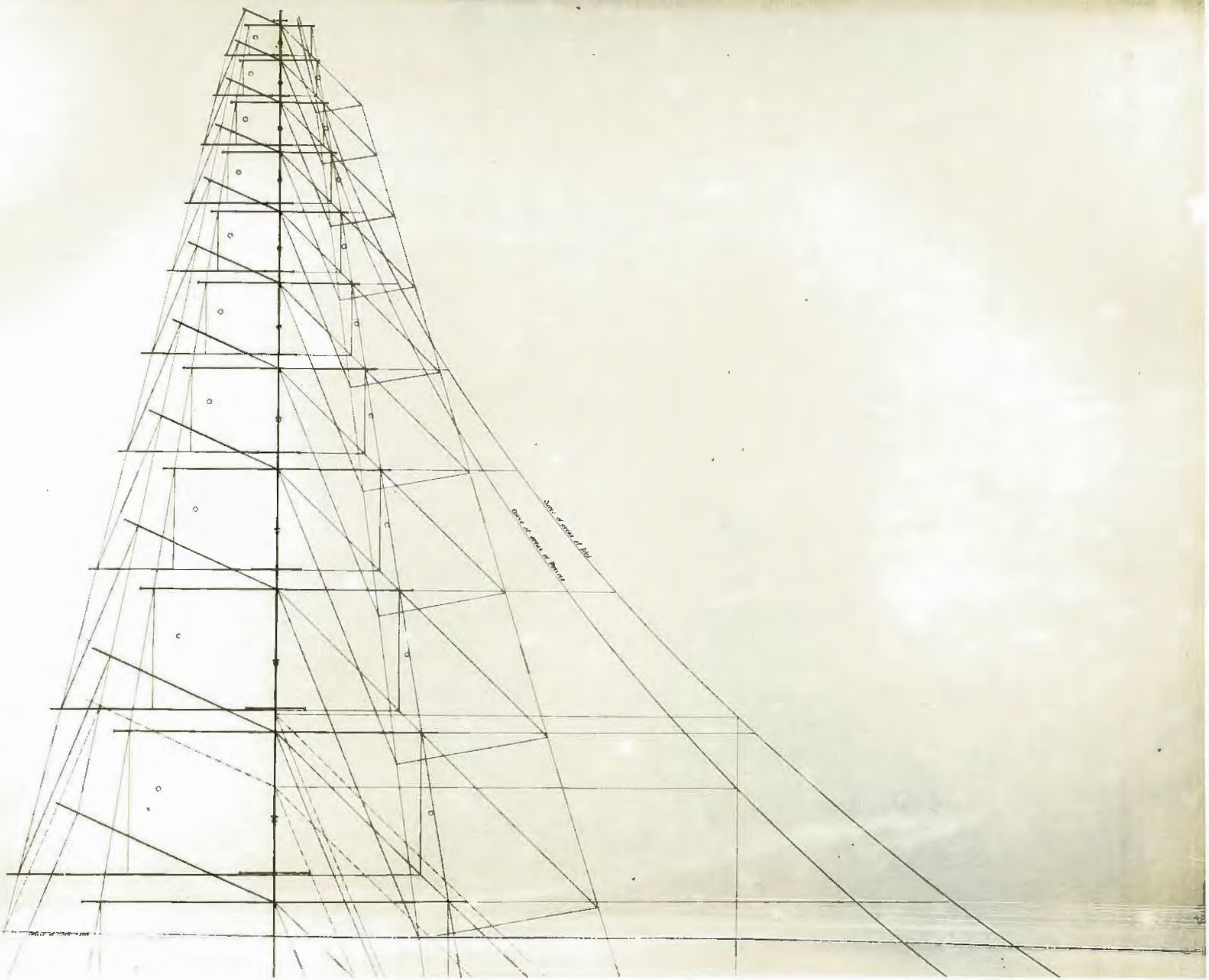
Square sails do not.

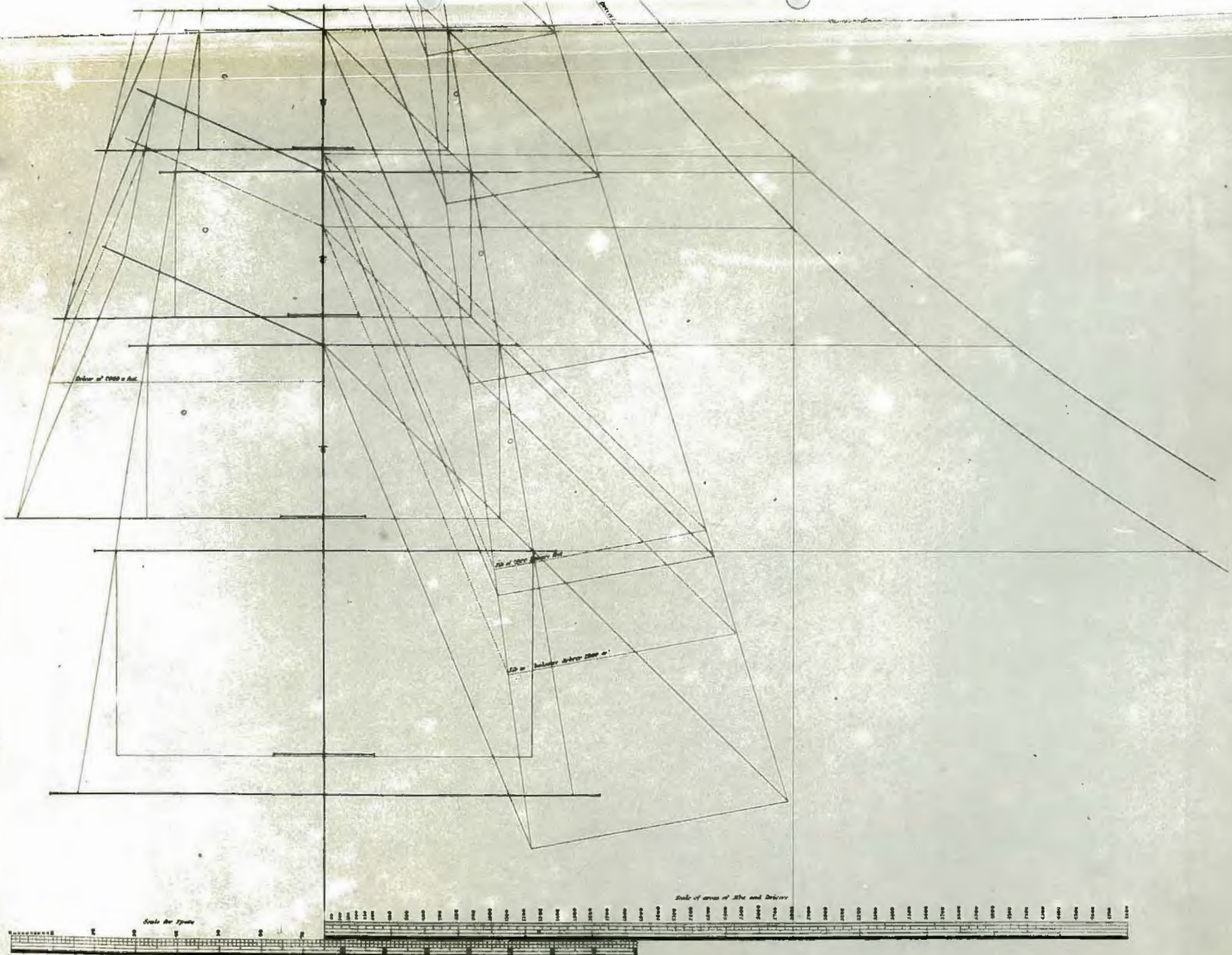
It must always remain a great point in favour of square-rigged vessels, that their sails pivot round their centres of effort, and keep their balance in every trim. On the other hand, it is a quality of the fore-and-aft rig to lie closer to the wind, and probably to yield a given sail area with a smaller quantity of top hamper, thus suiting well the chief purpose of modern sails, to serve as effective auxiliaries to the power of steam.

Iron masts and spars.

On the other hand, I may express my own strong conviction, that iron masts, spars, and rigging, are about to open up a new and important field of enterprise, and that the use of sails, worked by an auxiliary engine, will, in future, be introduced in iron ships of large size, on a scale not heretofore attempted.

Wooden clippers of 5000 tons have not proved successful, because the material is not suited to the size: but now that all the products of all countries are passing rapidly to other countries, and that the most distant nations, from opposite sides of the world, are pouring their superfluous wealth, in liberal streams, into the stores of those who most want it; now that remote peoples are becoming rich and well-to-do, receiving, in exchange for those productions they can best spare, those which they most want; when we see great fertilizing stores of food and raiment gathering and stagnating on opposite shores for want of transport, we may be sure that ships of untold size will come in as messengers of peace and plenty, and fly on wings of greater spread and power than heretofore, laden with the richest productions of the earth. For it is true of ships, above all other engines, that size is power, and speed, and thrift. Provided only there be enough work, and enough to pay for doing it, we shall soon build ships large enough for the traffic.





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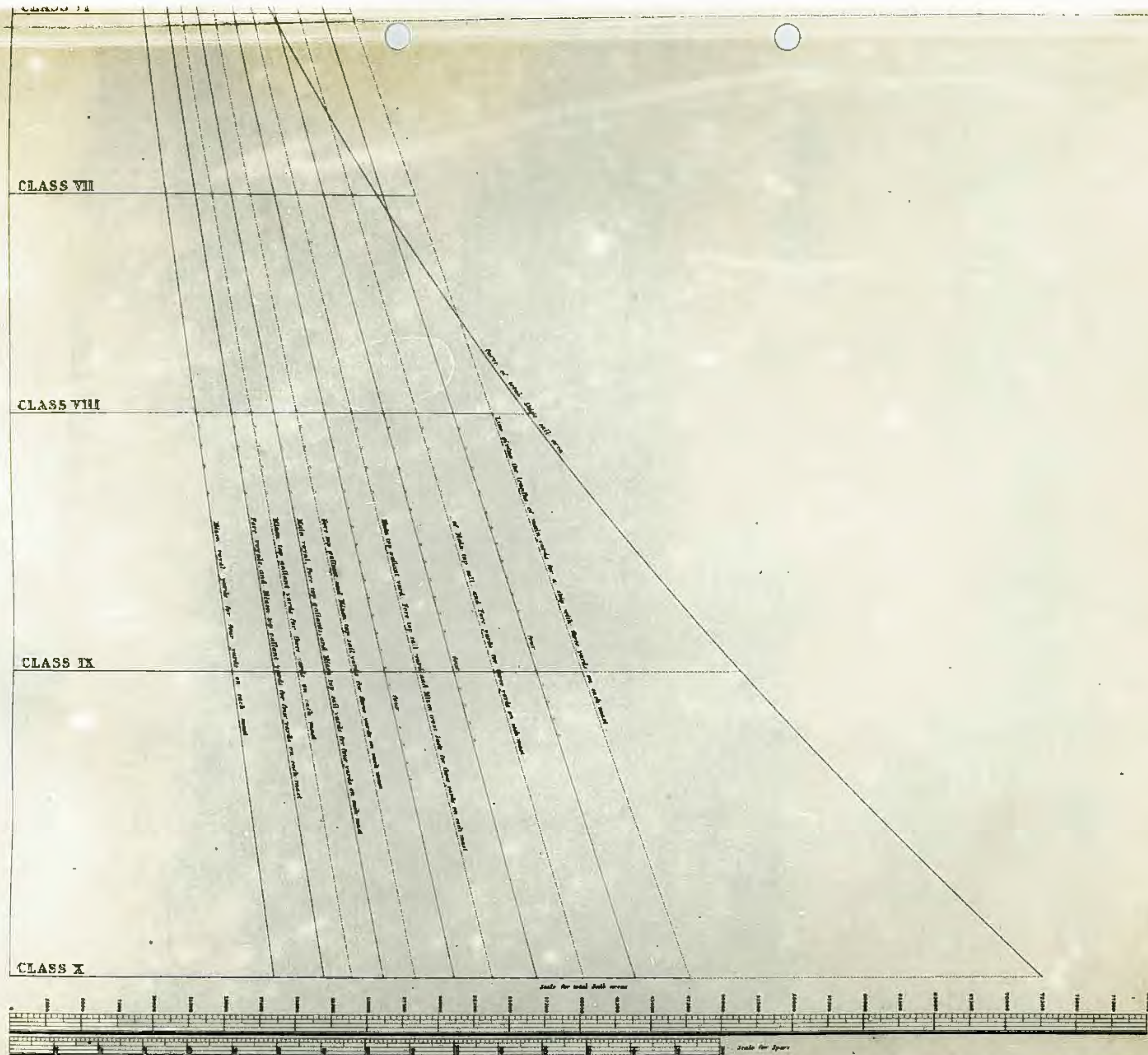

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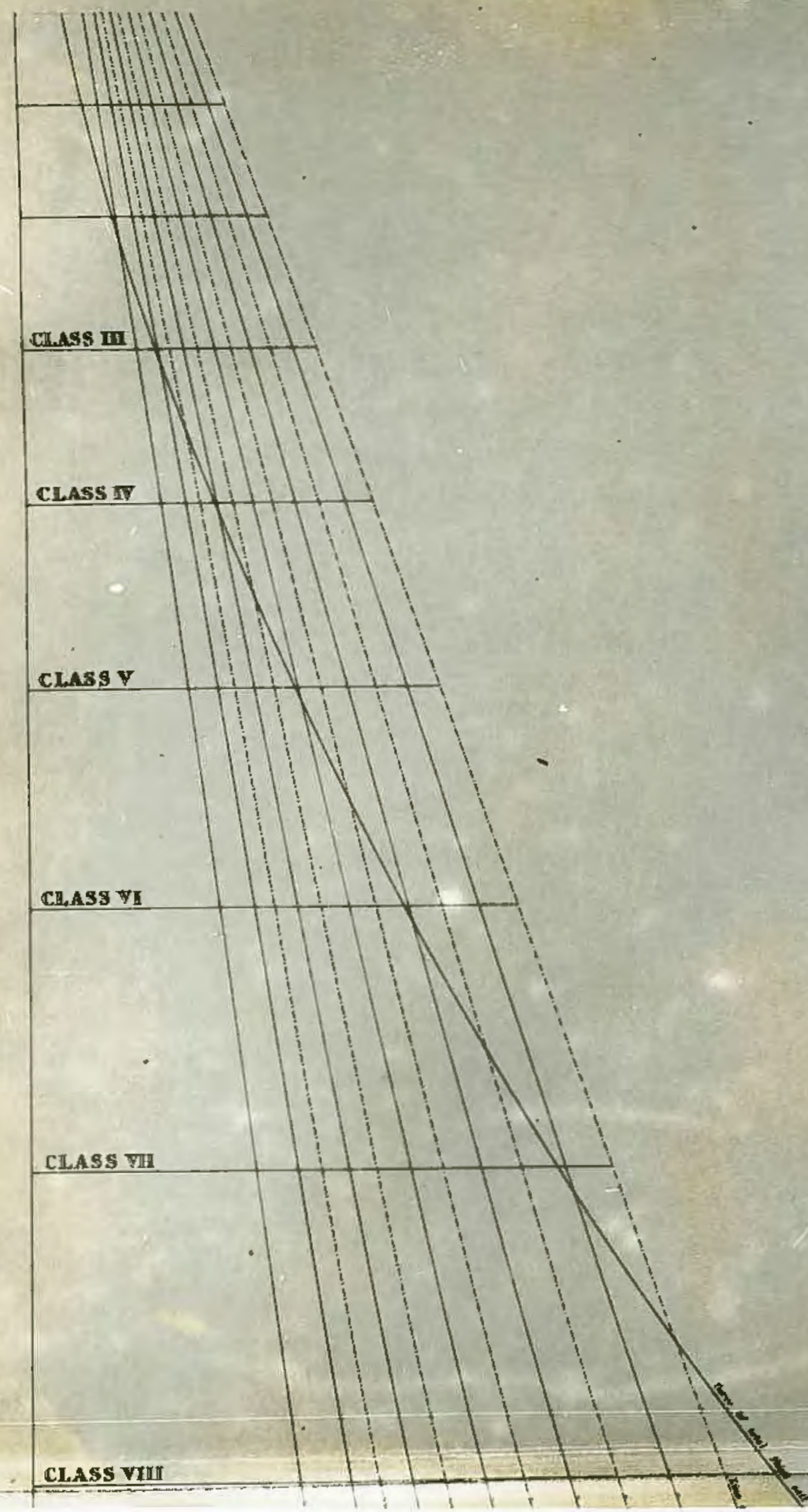
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CLASS VIII

Fig. 1.

120 Gun Ship of 1832

11060 □'

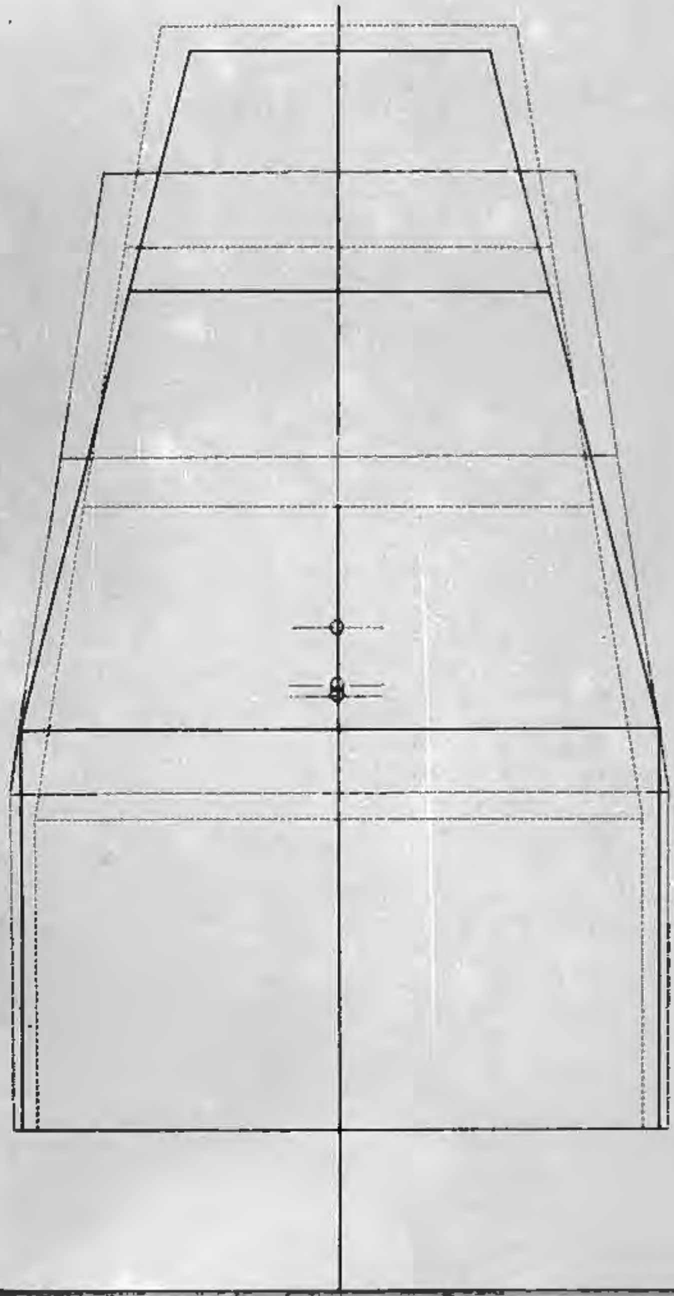
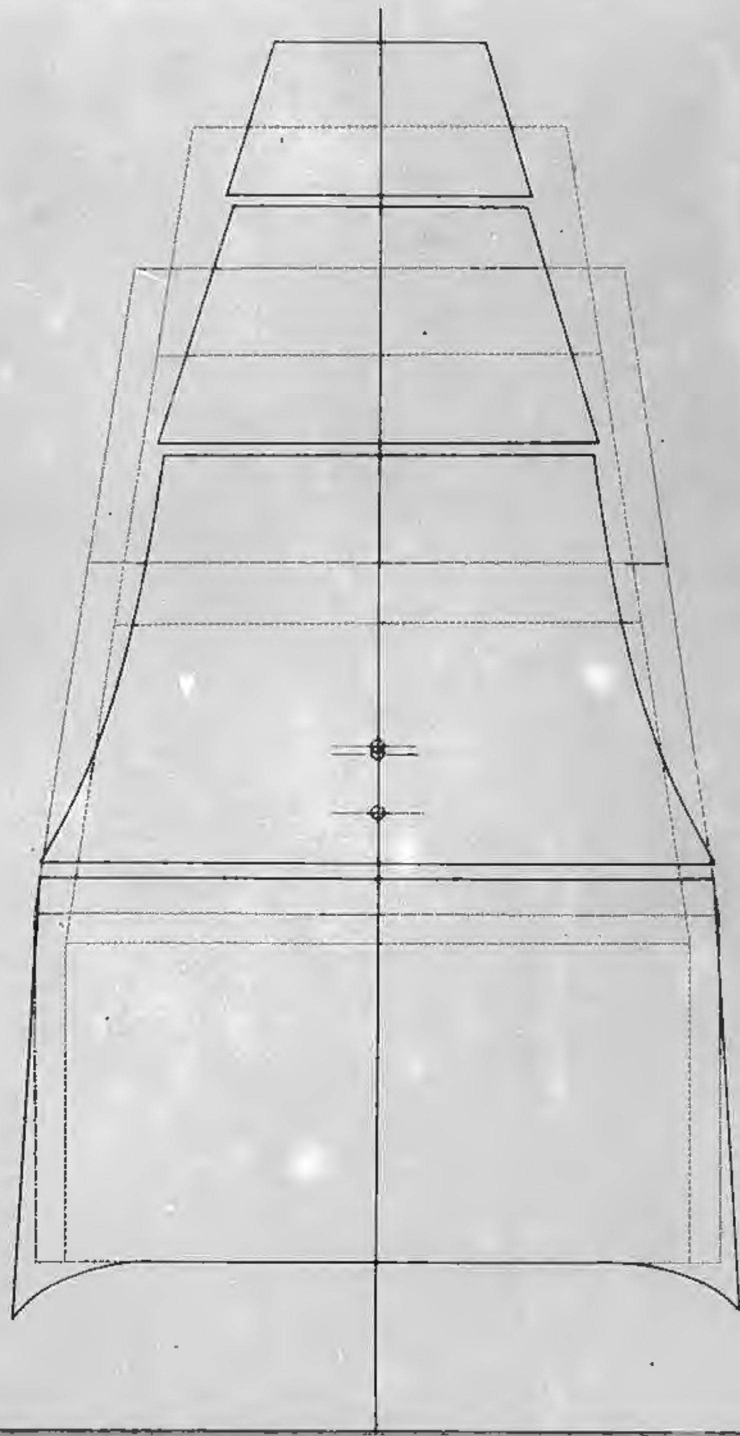


Fig. 2.

Warrior 1862.

11664 □'



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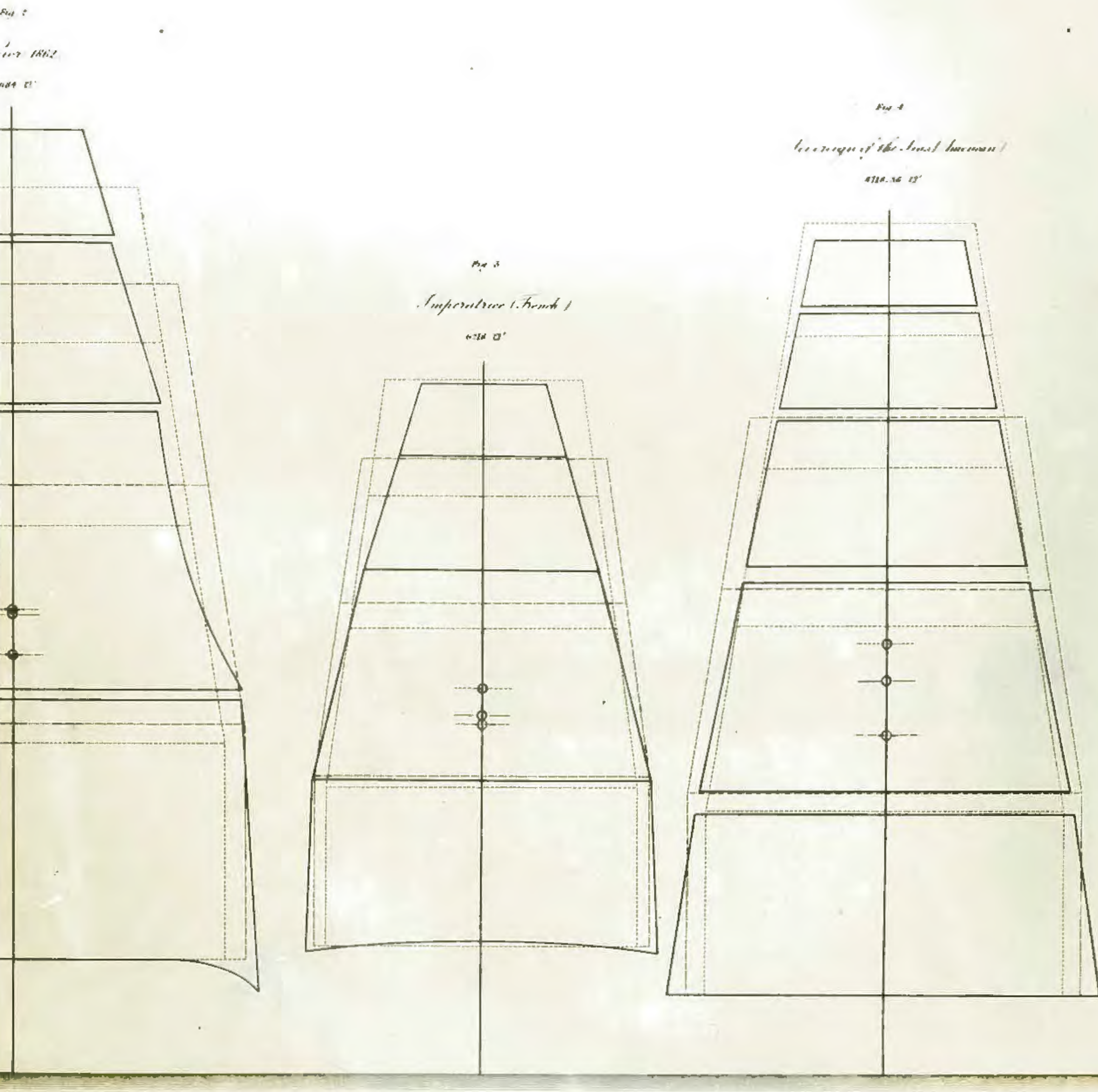

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PL. 15

Fig. 5.

Aberdeen Clippers

11783 □'

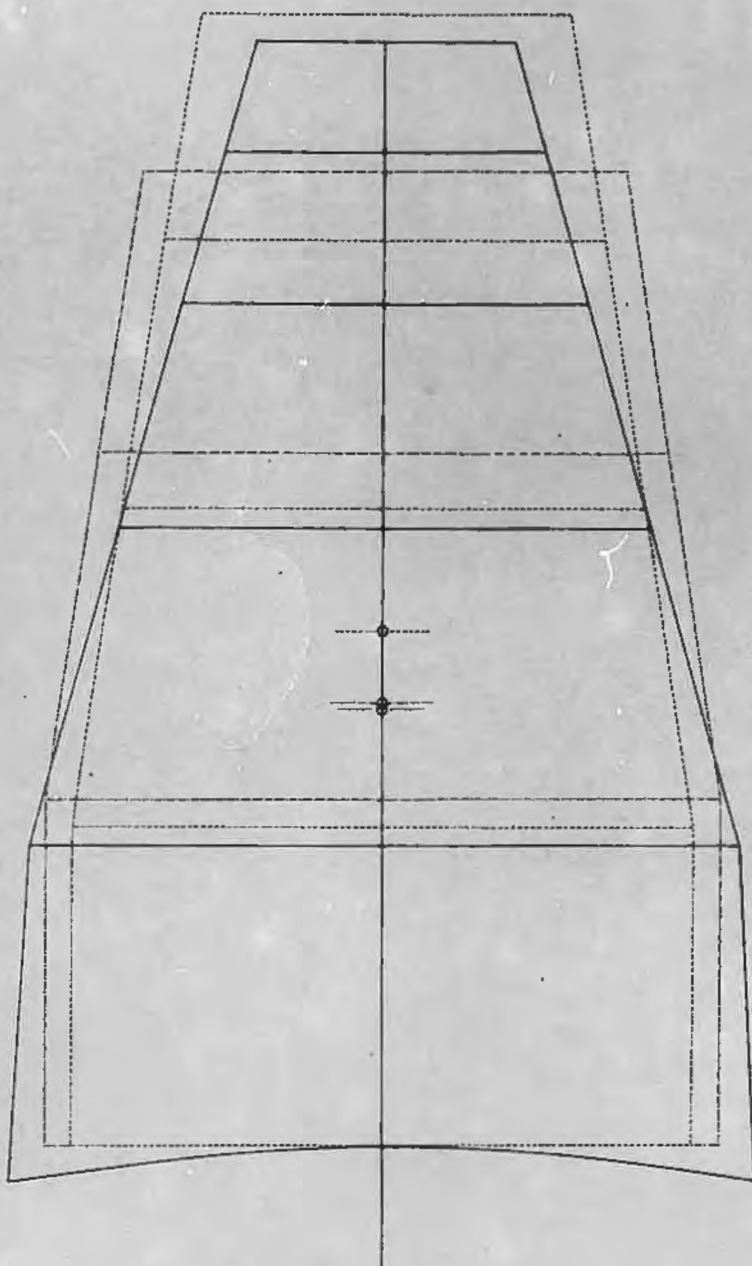
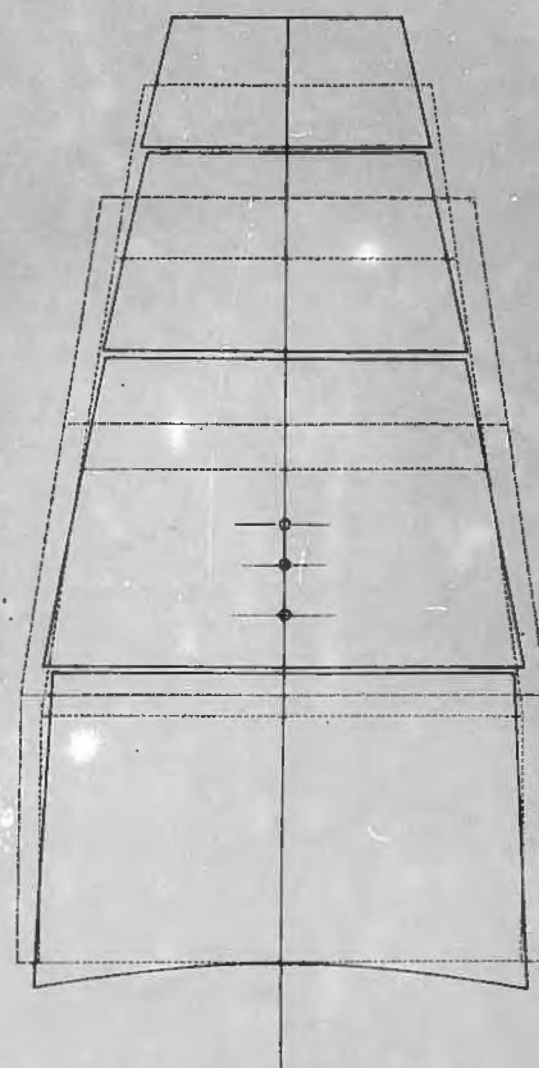


Fig. 6

Merchant Ship of 900 Tons.

7112 □'



Merchant S

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Fig 6

Merchant Ship of 950 Tons.

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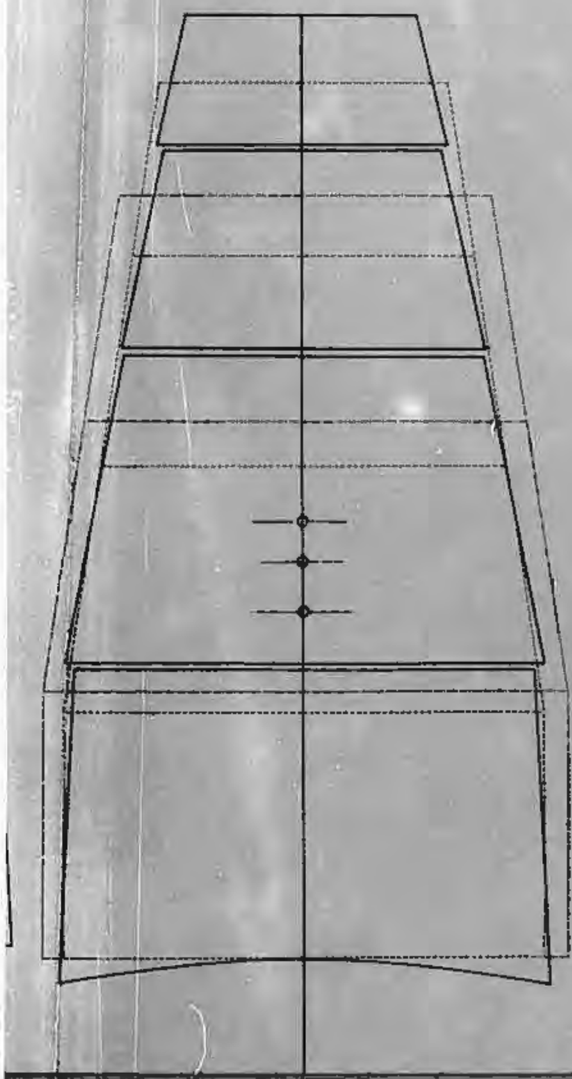


Fig. 7

Merchant Ship of 680 tons.

5330 □'

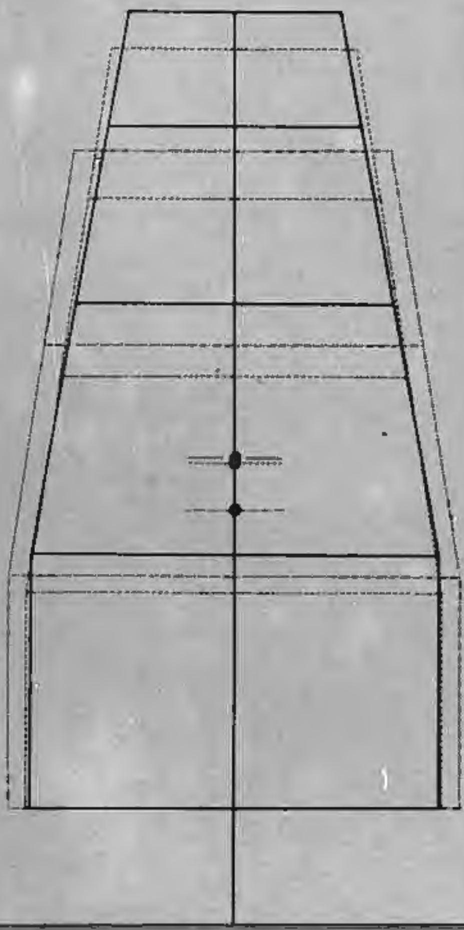
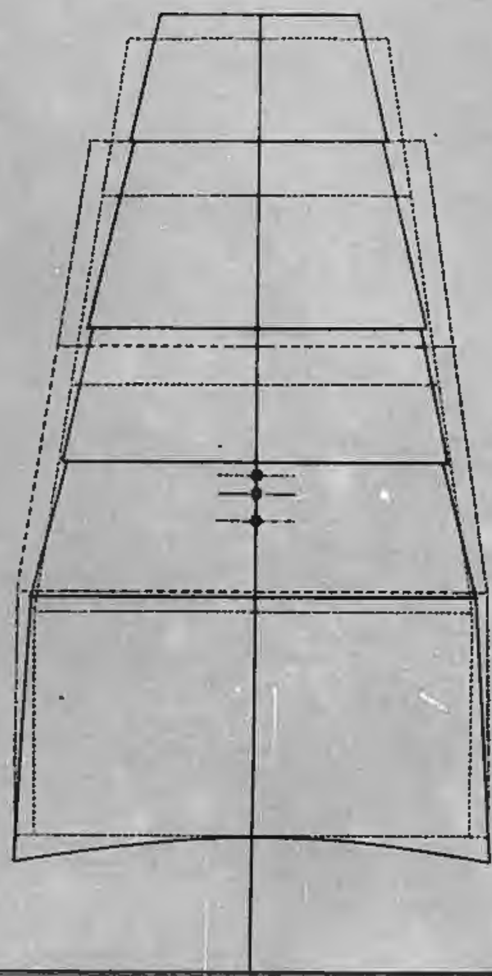


Fig. 8.

Merchant Ship of 900 tons.

5932.5 □'



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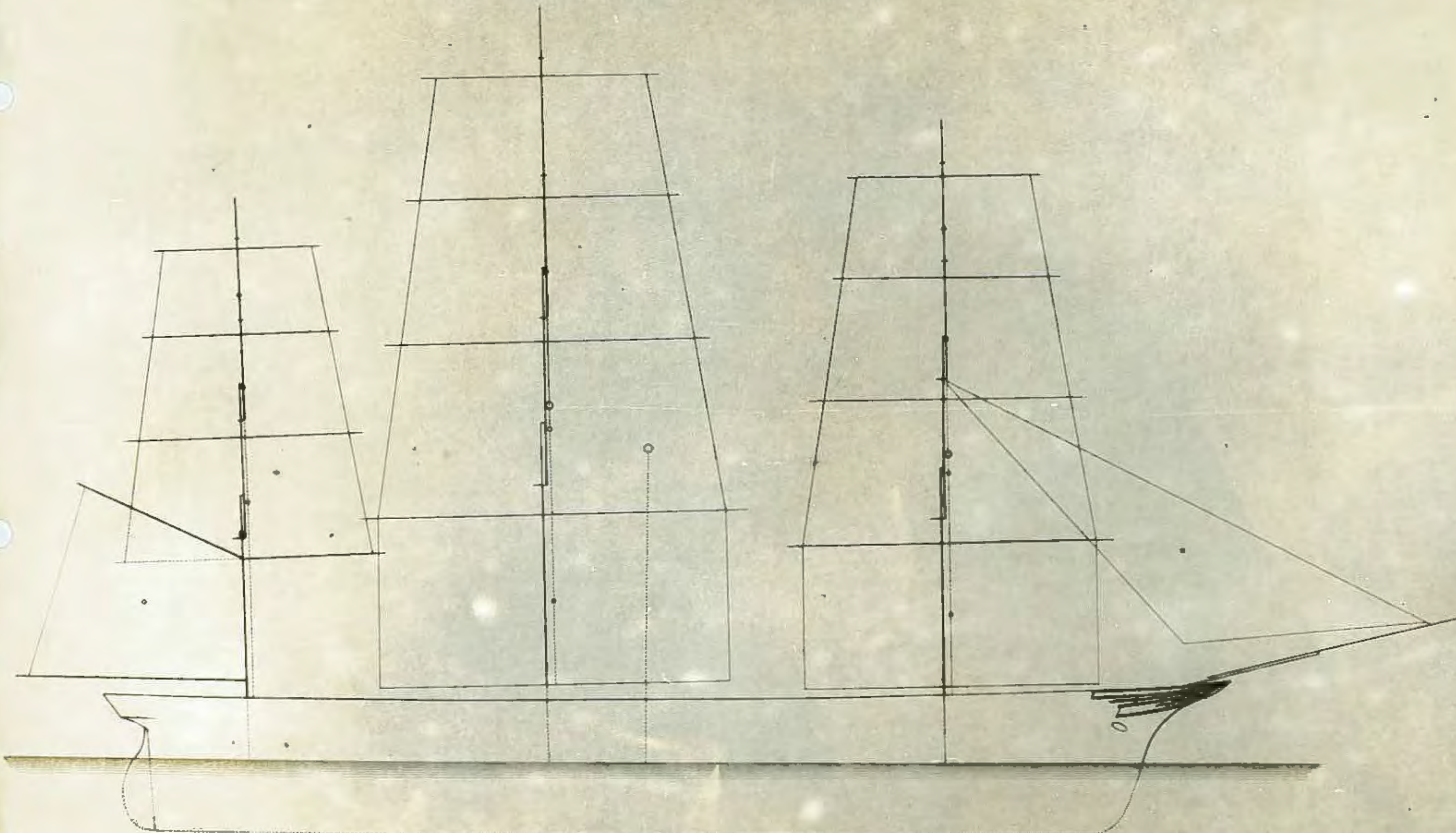

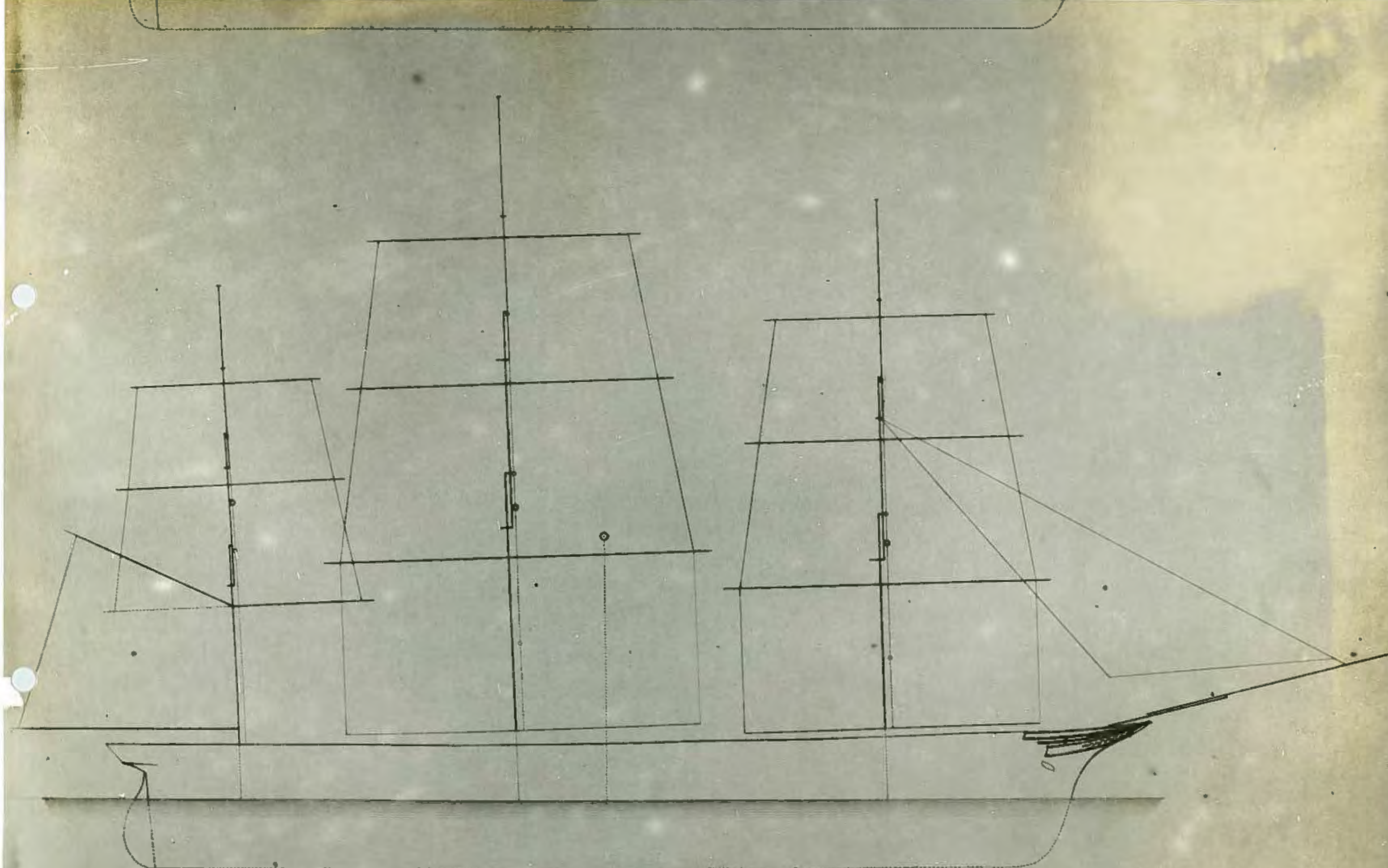

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