THE

ELEMEMTS

OF

NAVAL ARCHITECTURE:

OR, A

PRACTICAL TREATISE

ON

SHIP-BUILDING.

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CAREFULLY ABRIDGED

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A
PRACTICAL TREATISE
ON
SHIP-BUILDING.

CHAP. I.

General Proportions for Building.

NAVAL Architecture may be divided into three principal parts.

I. To give the ſhip ſuch a figure, or exterior form, as may ſuit the ſervice ſhe is deſigned for.

II. To find the true form of all the pieces of timber that ſhall be neceſſary to compoſe ſuch a ſolid.

III. To make proper accommodations for guns, ammunition, proviſions, and apartments for all the officers, and likewiſe for the cargo.

We ſhall at preſent only treat of the firſt of theſe, namely the exterior figure, and conſider it firſt, as it regards the bottom, that is, the part which lies under water, and may be called the quick-work; or, ſecondly, the part which is above water, and may be called the dead-work.

In order to give a proper figure to the bottom, all the qualities which are neceſſary to make a ſhip anſwer the ſervice for which ſhe is deſigned, ſhould be conſidered. A ſhip of war ſhould carry her lower tier of guns four or five feet out of the water. A ſhip for the merchants ſervice ſhould ſtow the cargo well, and both of them ſhould be made to go well, carry a good ſail, ſteer well, and lie to eaſily in the ſea.

Some eminent geometricians have endeavoured to find the form of a ſolid which may beſt anſwer all theſe qualities, and meet with the leaſt reſiſtance in dividing the fluid through which it is to paſs; but have not been able to reduce their theory to practice, by reaſon of the different poſitions a ſhip is obliged to be in when under ſail. The ſhip-builders, deſpairing to eſtabliſh this point by mathematical rules, have applied themſelves wholly to their own obſervations and experience, which may indeed ſupply the deficiencies of art; but though they may thereby diſcover that a ſhip has ſeveral bad qualities, it will not be eaſy to determine where the fault lies; for it may be owing to the rigging; and though the fault be not there, yet they cannot be certain in what particular part of the body it is. If their obſervations be aſſiſted by principles drawn from theory, it will conduce very much to attain their end.

As there have been ſeveral ſhips built which have ſeemed to anſwer all the ſervices for which they have been deſigned, ſome builders have made it their principal ſtudy to copy ſhips which have gained the applauſe of the ſeamen. This method they very improperly call the principal rule which ſhould be obſerved in building. Now, as the bodies of ſhips are very different from one another, ſo there are, by this means, as many different methods uſed; ſome chuſing one, and ſome another for a ſtandard. But it muſt be obſerved, that even though it were poſſible to find ſuch a body as ſhould give entire ſatisfaction, and have all the good qualities that ſhould be neceſſary to anſwer the ſervices propoſed, yet this could by no means be eſtabliſhed as a ſtandard by which other ſhips of different dimenſions may be built. For admitting we have a firſt rate of 100 guns, which by experience has been found to be a very good ſhip in all reſpects, yet we ſhould find ourſelves very much deceived, if we ſhould build a ſhip of 20 guns by making all the parts have the ſame proportion to one another, that they have in that of 100 guns.

The firſt thing to be done, in order to lay down the draught of a ſhip, is to determine the length, which ſhould be either on the lower gun deck, or at the load-water line; for there muſt be great care taken that there is a ſufficient ſpace betwixt the ports. This will oblige us firſt to fix the number and dimenſions of the ports, the diſtance of the aftermoſt port from the tranſom, and of the foremoſt from the ſtem, and the diſtance betwixt the ports. This article may be determined by the following tables:

A Table

A Table of the Number of Ports on each Side of a Ship, according to the Number of Guns, and the Weight of the Shot.

A Ship of 112 Guns.

Decks	Ports	Shot
1	15	48 or 36
2	16	24
3	15	12
Quarter	5	8
Forecastle	3	8
Poop	2	4

A Ship of 102 Guns.

Decks	Ports	Shot
1	14	36
2	15	18
3	14	12
Quarter, Forecastle, Poop	13	6

A Ship of 74 Guns.

Decks	Ports	Shot
1	13, 14	36
2	14, 15	18
Quarter, Forecastle	8, 8	8
Poop		4

A Ship of 64 Guns.

Decks	Ports	Shot
1	12, 13	24
2	13, 14	12
Quarter, Forecastle	7, 5	6

A Ship of 58 Guns.

Decks	Ports	Shot
1	12	18
2	13	12
Quarter, Forecastle	4	4

The Tiger.

Decks	Ports	Shot
1	11	18
2	12	8
Quarter	3	6
Forecastle	2	4

A Ship of 50 Guns.

Decks	Ports	Shot
1	11	18
2	12	12
Quarter	2	4

A Frigate of 46 Guns.

Decks	Ports	Shot
1	11	12
2	12	8

A Frigate of 32 Guns.

Decks	Ports	Shot
1	10	6
Quarter, Forecastle	6	4

A Frigate of 32 Guns.

Decks	Ports	Shot
1	4	8
2	10	6
Quarter, Forecastle	2	4

A Frigate of 32 Guns.

Decks	Ports	Shot
1	10	8
2	6	6

A Frigate of 28 Guns.

Decks	Ports	Shot
1	3	8
2	10	4
Quarter	1	4

A Frigate of 24 Guns.

Decks	Ports	Shot
1	10	6
Quarter	2	4

A Frigate of 22 Guns.

Decks	Ports	Shot
1	9	6
Quarter	2	4

Frigates of 20 Guns have 10 Ports on each side on one Deck. Shot 6 lb.

Vessels of 16 guns have 8 ports on one deck, the guns to carry 4 lb. shot.
Vessels of 12 guns have 6 ports on one deck, the guns to carry 4 lb. shot.

A Table of the Dimensions of the Ports, and Height of their Sells, according to the Weight of the Shot.

Shot	Hei. and brea. of ports.							Height of the ports				Sells			
lb.	f.	in.	l.	f.	in.	f.	in.	1st Deck		2d Deck		3d Deck		Quarter-Deck and Forecastle	
48	2	9		3	0 or	3	2	f.	in.	f.	in.				
36	2	8		3	0 or	3	1	2	2						
24	2	5		2	8 or	2	10	2	1	2	0				
18	2	4		2	7 or	2	8	1	11	1	9				
12	2	2	2	2	4 or	2	6	1	10	1	8	1	7		
8	1	9		1	11 or	2	3	1	8	1	6			1	5
6	1	6		1	8 or	1	11	1	7	1	6			1	5
4	1	4		1	6 or	1	9	1	5					1	3

A Table of the Number, Dimensions and Distances betwixt the Ports on the lower Deck; also the Distance betwixt the foremost Port and the Stem, betwixt the Aftmost and the Sternpost.

Ships Names.	N° of Ports	Breadth of Ports		Dist. betw. Ports		Foremost from Stem		Aftmost from Post		Length on L. Deck	
Amiable	13	2	8	7	6	13	4	9	0	147	
Invincible	13	2	8	7	4	12	4	9	0	144	
Achilles	12	2	8	7	8	18	2	10	6	145	
Toulouse	12	2	8	7	6	17	4	9	2	141	
Ardent, 64 guns	12	2	8	7	6	17	0	9	2	140	8
Fleuron, 64 guns	12	2	8	7	8	18	10	10	6	145	8
Dauphin Royal, 74 guns	13	2	10	7	7	18	2	10	0	156	

Note, An inch *French* measure is equal to 1 $\frac{1}{16}$ inch *English*, and is divided into twelve parts called lines, which are divided into twelve parts, called points.

The next thing to be done is to establish the breadth by the midship beam; the builders are pretty much divided in proportioning this to the length. Most of them conform to dimensions taken from ships of the same burthen, and designed for the same service.

After these two dimensions are determined, the depth of the hold must be fixed, which in most ships is half the breadth; but the form of the body should be considered; for a flat floor will require less hold than a sharp one. The distances likewise between the decks must be determined. The following table may be very useful towards ascertaining the three aforesaid dimensions.

A Table

A Table of the Length, Breadth, and Depth in Hold of the following Ships.

Ship's Names	Guns	Length at load-water line		Breadth		Depth in the Hold	
		feet	in.	f.	in.	f.	in.
Monarque	74	165		43		20	6
Intrepide	74	165		43		20	6
Alcide	64	149		40	6	19	4
Renommée	30	120		31	8	15	7
Palme	12	85		22	6	10	5
Soleil Royal	80	182		48		23	
Formidable	80	178		44	10	21	10
Tonnant	80	168		46		23	
Sceptre	74	165		43		20	6
Superbe	74	153	6	42	8	21	
Esperanse	74	154		42		21	
Magnifique	74	165		43		20	6
Northumberland	68	149		40		20	
Lis	64	149		40		19	
Hercule	64	149		40	6	19	4
Protee	64	150		40	6	19	4
Illustree	64	150		40	8	20	
Opinatre	64	150		40	4	19	5
Dragon	64	149		40		19	
Leopard	64	146		39	6	18	6
St Laurent	60	145		39	4	18	8
Amphion	50	145		39		18	
Amazon	44	148					
Brillant	50	135		35			
Arc-en-Ciél	50	135		37		17	9
Tigre	52	131		37		17	
Alcion	50	132		35	4	18	
Aquilon	46	127		34		17	
Junon	46	130		36	6	16	6
Favorite	36	127		33		14	
Anglesea	32	121	8	33	6	16	
Serenne	30	118		31	8	15	9
Emenaude	28	118		31	8	16	
Galatée	24	110		29		14	6
Mutine	24	110		29		14	6
Cumberland	24	102		26		13	
Marshal Saxe	22	100		27		14	
Anemone	12	84		22		9	

Ship's Names	Guns	Length	Breadth		Depth	
		feet	f.	in.	f.	in.
Amarante	12	84	22		9	
Elizabeth	64	143	38	4	18	
Brave	80	172	44		21	
Floriffant	74	165	45		22	6
Couronne	74	167	44		22	7
Hardi	64	149	40	6	20	9
Aigle	50	144	39		19	6
Hermione	26	126	33	8	13	8
Jufte	70	151	42		21	
Triponne	26	114	31	8		
Panthere	20	108	28	6		
Badine	6	66	18	4		

We may then proceed to fix the length of the keel, which will oblige us to determine the rake of the ftem and poft, for which the builders have given us no invariable rule, they being very much divided in their opinions; for where fome have given a rake of 18 or 20 feet, others have given none at all. The height of the ftem and wing-tranfom muft alfo be determined, which may be regulated by the decks.

The difference betwixt the draught of water abaft and that afore, fhould likewife be confidered; for though fome imagine that when a fhip is loaded her keel fhould be parallel to the furface of the water, yet in many cafes it will be found neceffary that the keel abaft fhould be deeper in the water that it is afore. This will give the rudder more power, and thereby contribute to make a fhip fteer well; but this difference of the draught of water is intirely arbitrary; for in large fhips fome have given five, whereas others have given but three, or even two feet of difference. Though I could not procure the true difference of the draught of water of many fhips of war, yet I am affured that the following are pretty exact.

The Difference of the Draught of Water in the following Ships.

	feet	in.		feet	in.
Northumberland	1	2	Panthere	1	4
Augufte	1	6	Couronne	2	1
Aloze	1	0	Triponne	2	
Hermione	2	0	Renommée	1	4
Amazone	1	6	Tigre	3	2
Badine	0	10	Intrepide	2	3
Palme	1	4	Alcide	2	0

The

The length of the wing transom must also be determined; some make it $\frac{2}{3}$ of the main breadth; but this is likewise arbitrary, the broader a ship is abaft, the more room there will be for accommodations for the officers; but this will be disadvantageous to her sailing upon a wind.

The following Examples will be sufficient to fix the Length of the Wing transom for any Ship.

For a ship of 110 guns, $\frac{2}{3}$ of the main breadth, and 3 lines more to every foot.
102 guns, $\frac{2}{3}$ of the main breadth, and 8 inches more.
82 guns, $\frac{2}{3}$ of ditto.
74 guns, 7 inches, 9 lines for every foot in breadth.
62 guns, 7 inches, 8 lines for ditto.
56 guns, 7 inches, 7 lines, 9 points for ditto.
50 guns, 7 inches, 6 lines, 6 points for ditto.
46 guns, 7 inches, 6 lines for ditto.
32 guns, 7 inches, $5\frac{1}{2}$ lines for ditto.
For a frigate of 22 guns, 7 inches 4 lines.
12 guns, 7 inches.

Some, without regarding these proportions, make the wing transoms of the first and second rates two thirds of the breadth, and for all the rest one foot less.

After these dimensions are determined, the timbers may be considered which form the sides of the ship. A frame of timbers is composed of one floor timber, two or three futtocks and a top timber on each side: All these being united together, and secured by cross-bars, form a circular inclosure, that which incloses the greatest space is called the midship frame: The curve of this frame is inverted at the lower part, so that the floor timber will be somewhat hollow in the middle, whereby the ends will form a very obtuse angle; but this angle decreases the farther the frames are removed from the midships, in such a manner, that the foremost and aftermost will become very sharp, and form a very acute angle. These floor timbers are called crutches.

The builders seem to agree nearly as to the length of the midship floor timber, making it generally half the length of the main beam; but they differ very much about the rising of it, some chusing a flat and others a sharp floor. And if we consider the advantages and disadvantages that attend the one and the other, we shall not be much surprized to find them so much divided upon this article; for it is certain, the more rising a ship has, she will hold the better wind, but then this will occasion her to draw more water, which will be sometimes attended with very great inconveniences.

A Table

A Table of the rising of the Midship Floor Timbers.

Guns	f.	in.	lines.		Guns	f.	in.	lines	
110	0	0	10	to every foot in length.	56	0	1	4	to every foot in length.
102	0	0	10½		32	0	1	4	
86	0	1	0		28	0	1	4	
74	0	1	0		22	0	1	6	
62	0	1	0½		16	0	1	6	

Note, *What we have here rendered the rising of the floor timbers, the author calls the* Aculement, *and makes a distinction betwixt it and the rising, which we shall see when we come to form the frames.*

They differ as much in determining the station of the midship frame, some placing it before, others at the middle of the ship; others again have two floor timbers of equal length, and rising, one of which is placed exactly in the middle, or the breadth of the timber before the middle, and the other at a proper distance before it. Those who place it before, alledge, that if a ship is full forward, after she has once opened a column of water, she will afterwards meet with no resistance, and the water will easily unite abaft, and by that means force the ship a-head, and have more power on the rudder the farther it is from the centre of gravity; and besides this comes nearest the form of fishes, which should seem to be the most advantageous for dividing fluids.

Those who would have it placed in midships say, that by that means the water-lines forward will be easier, and of consequence properer for dividing fluids; and that there will be space enough betwixt it and the rudder for forming very fair water-lines, so that the water will easily unite at the rudder; and besides it will be easier by this means to balance the fore body and after body; and in general the building will by this means be very much facilitated; so that, in my opinion, it will be properest to place it very near the middle, though it is the general practice to place it before it.

After the rising of the midship floor timber is determined, we may then proceed to fix the height of the rising line of the floor abaft on the post, and afore upon the stem.

Now, as all ships are narrower abaft and afore, than in midships, the other floor timbers will of consequence be shorter and have a greater rising, which will be still increasing till it ends on the post and stem. There are several different methods used by the builders to settle the height of this line. Some imagine, that by narrowing the floor abaft, which will occasion the rising line to be high upon the post, the ship will

will thereby steer better, and besides, the water which is opened by the midship frame will then have a greater pressure upon the after part of the ship, and thereby contribute to her sailing: Yet these arguments are of very little weight; for if we only consider the steerage, it is certain, that the higher the rising line is carried abaft, and the narrower a ship is, the water will have the easier passage, and more power upon the rudder. But then we shall thereby run the risk of falling into two great inconveniencies; for, by this means, we take away the buttock, which is the only thing we have to support all the weight of the after part of the ship; neither shall we be able to give a proper balance betwixt the fore and after part; and when the fore and after parts are not duly balanced, it will occasion a ship to pitch very hard, and be in danger of being frequently pooped by the sea when it runs high. To prevent these inconveniencies, it will be proper to give all ships, especially the large sort, a full buttock. As to the height of the rising line afore, it should be determined by the form of the water lines; but before this can be done, the timbers must be formed.

Note, What we have rendered the rising line of the floor, our author calls les façons, *which, he says, is the increase of the* acculement, *the extreme points of which upon the perpendicular of the stem and post are now to be determined.*

The height of the lower deck is the next thing to be considered: It is determined in midships by the depth of the hold, and some builders make it no higher at the stem; but they raise it abaft more than it is in midships, as much as the load-water mark abaft exceeds that afore. As to the height betwixt decks, it is altogether arbitrary, and must be determined by the rate of the ship, and the service that she is designed for.

We come now to consider the upper works, or all that is above water, called the dead-work: And here the ship must be narrower, so that all the weight that lies above the load-water line will thereby be brought nearer the middle of the ship; by which means she will strain less by working the guns, and the main sail will be easier trimmed when the shrouds do not spread so much. But though these advantages are gained by narrowing a ship above water, great care must be taken not to narrow her too much, for there must be sufficient room upon the upper deck for the guns to recoil. The security of the masts should likewise be considered, which requires sufficient breadth to spread the shrouds, though this may be assisted by enlarging the breadth of the channels.

CHAP. II.

Of the Scantlings and Dimenfions of the principal Pieces of Timber in a Ship.

ALTHOUGH it is not my intention, as I obferved in the beginning of the laft chapter, to treat of all the pieces that compofe the fhip, yet I think it neceffary to fay fomething of the principal pieces. I fhall therefore, in the following plate, lay down each piece by itfelf, by which means we fhall fee the length of the fcarphs, and in what manner they are to be joined together.

Explanation of Plate I.

I.

A. The keel in four pieces, to be well bolted together, and clinched.

II.

I. The fore foot, one end of which is fcarphed to the fore end of the keel, of which it is a part, and the other end makes a part of the ftem, to which it is fcarphed.

III.

u u. Two pieces of dead wood, one afore and the other abaft, fayed upon the keel.

IV.

C C. The ftem in two pieces, to be fcarphed together.

V.

E E. The apron in two pieces, to be fcarphed together, and fayed on the infide of the ftem, to fupport the fcarph of the ftem; for which purpofe the fcarph of the apron muft be clear from that of the ftem.

VI.

o. The ftemfon in two pieces, to fupport the fcarph of the apron.
o. The falfe poft, which is fayed to the fore part of the poft.

VII.

B. The ftern poft: It is tenanted into the keel, to which it is faftened with a knee.

D. The

VIII.

D. The back of the post, which is likewise tenanted into the keel and well bolted to the post; the design of it is to give sufficient breadth to the post, which seldom can be got broad enough in one piece.

IX.

F. The knee which fasteneth the post to the keel.

X.

N. The wing transom. It is fayed across the stern post, and bolted to the head of it: The fashion pieces are fastened to the ends of it; underneath this and parallel to it is the deck transom.

XI.

O O. Two transoms fastened to the stern post and fashion pieces, in the same manner as the wing transom.

XII.

P. The transom knee, which fasteneth it to the ship's side.

XIII.

Q. The fashion piece, of which there is one on each side: Their heels are fastened to the stern post at the height of the floor ribbands, and their heads are fastened to the wing transom.

XIV.

T. A floor timber. It is laid across the keel, to which it is fastened by a bolt through the middle.

XV.

K. The lower Futtock.

XVI.

T T T T T. 2d, 3d, 4th futtocks and top timbers. These shew the proper length and scarph of the timbers in midships frame.

XVII.

U U. Riders. These are fayed in the inside of the ship, and consist of floor and futtock riders.

XVIII.

Z. The keelſon. This is made of two or three large pieces of timber ſcarphed together in the ſame manner as the keel. It is placed over the middle of the floor timbers, and ſcored about an inch and an half down upon each of them.

XIX.

R S. Breaſt-hooks. Theſe are fayed in the inſide to the ſtem, and to the bow on each ſide of it, to which they are faſtened with proper bolts. There are geneally four or five in the form of R in the hold, one in the form of S into which the lower deck planks are rabbited; there is one right under the hawſe holes, and another under the ſecond deck.

XX.

X, Y, Z. are thick planks which are fayed in the inſide, and ſtretch fore and aft to ſtrengthen the ſcarphings of the timbers.

XXI.

Z. are thick planks in the inſide, called clamps, which ſupport the ends of the beams.

XXII.

15, 15, 15, 15, 15, are the wales. They are planks broader and thicker than the reſt, which are faſtened to the outſide of the ſhip in the wake of the decks. We ſhall have occaſion in another place to ſhow how they are laid down in a draught. As to the plank below the wale to the keel, and above it to the top of the ſide, we refer to the ſection of one half of the midſhip frame, as laid down in the plate.

XXIII.

d, d, d, d, d, d, d, are knees. Theſe are crooked pieces of timber conſiſting of two arms, which form an angle, either within or without a ſquare, or exactly ſquare; their uſe is to faſten any two pieces together, as the beams to the ſhip ſides.

XXIV.

19. The rudder. This is joined to the ſtern poſt by the rudder irons, upon which it turns round in the googings which are faſtened upon the ſtern poſt for that purpoſe. There is a mortiſe cut out of the head of

it,

it, into which a long bar is fitted, called the tiller, by which the rudder is turned from one side to the other.

XXV.

23. The cat heads. These are two large pieces of square timber, one on each side of the bowsprit. They project out before the bow, in order to keep the anchor clear of the ship, which is hove up by a rope called the cat fall, that passes through shivers in the outer end of the cat-head: Their inner ends are fastened upon the forecastle.

XXVI.

m, *m*, *i*, *i*, *i*, are the several pieces which compose the knee of the head; the lower part *m* is fayed to the stem, the heel of it is scarphed to the head of the forefoot; it is fastened to the bows by two knees called cheeks, in the form of ʃ, and to the stem by a knee called a standard, in the form of K.

XXVII.

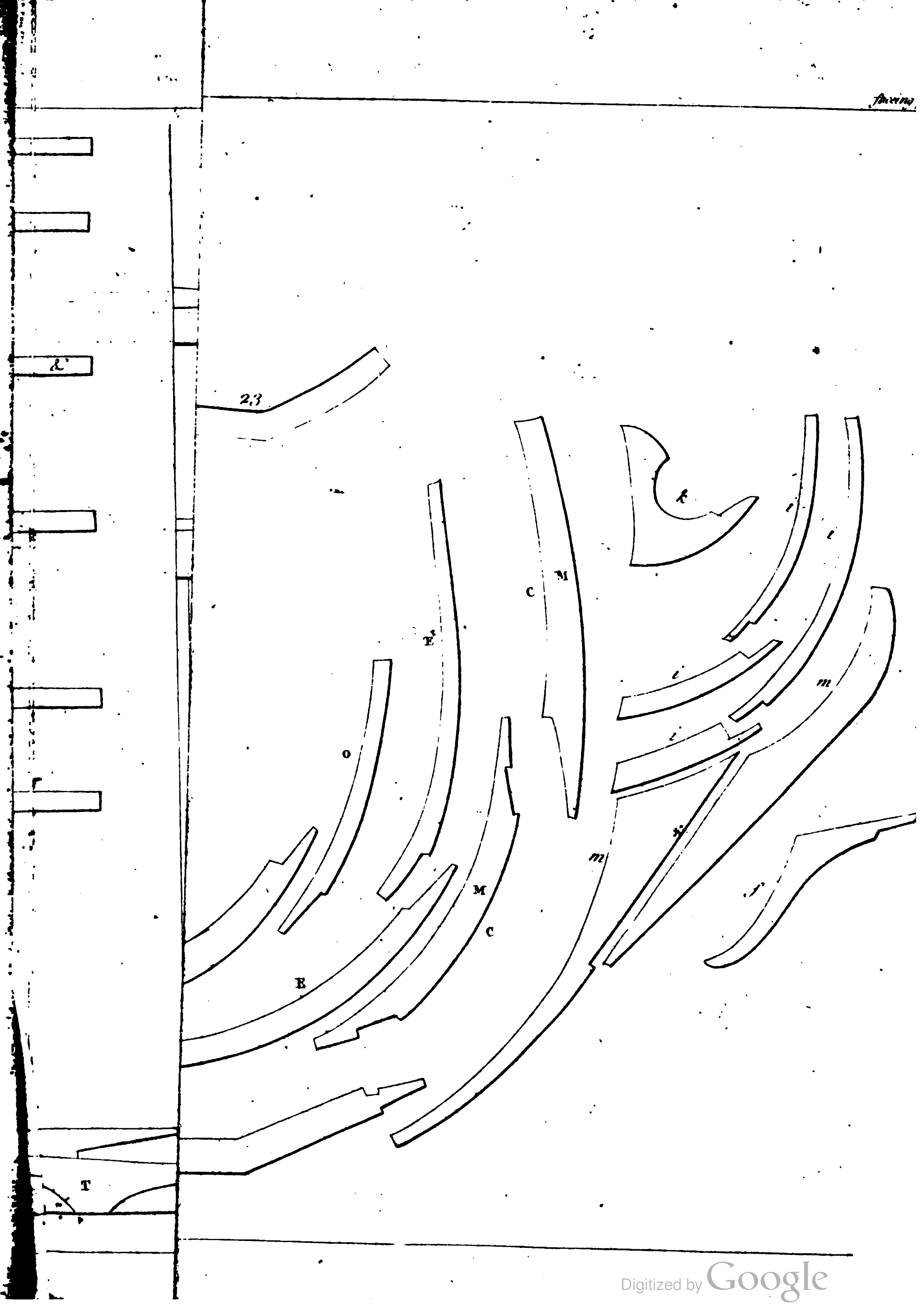
Beams &c, *a*, X Y, are large pieces of timber which support the planks of each deck.

Having thus explained all the pieces in the plate, we shall in the following table give their scantlings.

SCANTLINGS of the principal Pieces of Timber in a SHIP.

	f. in.	f. in.	f. in.	f. in.	f. in.	f. in.	f. in.	f. in.	f. in.	f. in.	f. in.	f. in.
BREADTH of the SHIPS.	48 0	46 0	44 0	42 0	40 0	38 0	36 0	34 0	32 0	30 0	27 0	24 0
LENGTH of the SHIPS.	175 0	169 11	163 9	157 6	151 0	144 7	138 0	131 3	124 5	117 6	106 10	96 0
NAMES of the PIECES.	f. in. l.	f. in. l.	f. in. l.	f. in. l.	f. in. l.	f. in. l.	f. in. l.	f. in. l.	f. in. l.	f. in. l.	f. in. l.	f. in. l.
BEAMS. First deck square	1 4 0	1 3 6	1 3 0	1 2 6	1 2 0	1 1 6	1 1 0	1 0 4	0 11 10	0 11 2	0 11 7	0 10 0
BEAMS. Second deck square	1 1 6	1 0 11	1 0 5	0 11 10	0 11 3	0 10 9	0 10 2	0 9 7	0 9 1	0 8 6	0 0 0	0 0 0
BEAMS. Quarter deck and forecastle Moulded	0 10 3	0 9 9	0 9 3	0 8 9	0 8 3	0 7 9	0 7 3	0 6 9	0 9 3	0 5 9	0 5 3	0 4 9
BEAMS. Quarter deck and forecastle Sided	0 11 3	0 10 10	0 10 6	0 10 1	0 9 8	0 9 4	0 8 11	0 8 6	0 8 2	0 7 9	0 7 5	0 7 0
BEAMS. Poop Moulded	0 7 6	0 7 1	0 6 9	0 6 5	0 6 1	0 5 8	0 5 4	0 5 0				
BEAMS. Poop Sided	9 3 9	0 9 2	0 8 9	0 8 6	0 8 3	0 8 0	0 7 9	0 7 6				
BREAST HOOK sided on the lower deck	1 3 6	1 3 0	1 2 7	1 2 2	1 1 8	1 1 3	1 0 9	1 0 4	0 11 10	0 11 5	0 10 10	0 10 6
CLAMPS, as broad as can be had, and half as thick as the timbers to which they are fastened												
KEEL Deep	1 7 0	1 6 5	1 5 11	1 5 4	1 4 10	1 4 3	1 3 9	1 3 2	1 2 8	1 2 1	1 1 6	1 1 0
KEEL Broad	1 5 0	1 4 4	1 3 8	1 3 0	1 2 4	1 1 8	1 1 0	1 0 5	0 11 9	0 11 2	0 10 7	0 10 0
KNEES. First deck Sided	1 3 0	1 2 4	1 1 8	1 0 11	1 0 3	0 11 7	0 10 11	0 10 3	0 9 6	0 8 10	0 8 2	0 7 6
KNEES. First deck Moulded	1 6 0	1 5 3	1 4 6	1 3 9	1 3 0	1 2 3	1 1 6	1 0 9	1 0 0	0 11 3	0 10 6	0 9 9
KNEES. Second deck Sided	1 1 0	1 0 3	0 11 6	0 10 9	0 10 0	0 9 3	0 8 6	0 7 9	0 7 0	0 6 3		
KNEES. Second deck Moulded	1 3 6	1 2 3	1 1 5	1 1 8	0 11 9	0 11 1	0 10 4	0 9 7	0 8 9	0 8 4		
KNEES. Quarter deck and forecastle Sided	0 9 3	0 8 10	0 8 5	0 7 11	0 7 6	0 7 1	0 6 8	0 6 3	0 5 9	0 5 4	0 4 11	0 4 6
KNEES. Quarter deck and forecastle Moulded	0 11 6	0 11 0	0 10 7	0 10 2	0 9 8	0 9 3	0 8 0	0 8 4	0 7 10	0 7 5	0 6 11	0 6 6
KNEES. Poop Sided	0 6 0	0 5 8	0 5 5	0 5 2	0 4 10	0 4 7	0 4 3	0 4 0				
KNEES. Poop Moulded	0 8 3	0 7 11	0 7 7	0 7 3	0 6 11	0 6 8	0 6 4	0 6 0				
KNEES. Transom Sided	1 3 0	1 2 6	1 2 1	1 1 8	1 1 2	1 0 9	1 0 3	0 11 10	0 11 4	0 10 11	0 10 5	0 10 0
KNEES. Transom Moulded	1 6 0	1 5 6	1 5 0	1 4 6	1 4 0	1 3 6	1 3 0	1 2 6	1 2 0	1 1 6	1 1 [illegible]	1 0 6
Planchere thick	0 5 0	0 4 9	0 4 6	0 4 4	0 4 1	0 3 10	0 3 8	0 3 5	0 3 2	0 2 11	0 2 9	0 2 6
Stem Twartships	1 5 0	1 4 4	1 3 9	1 3 1	1 2 5	1 1 10	1 1 2	1 0 6	0 11 11	0 11 3	0 10 8	0 10 0
Stem Fore and aft	1 9 0	1 8 5	1 7 10	1 7 3	1 6 8	1 6 0	1 5 5	1 4 10	1 4 3	1 3 8	1 3 1	1 2 6
Ditto, false or apron thick	1 2 0	1 1 5	1 0 11	1 0 4	0 11 10	0 11 3	0 10 9	0 10 2	0 9 8	0 9 1	0 8 6	0 8 0
STERN-POST Thick	1 5 0	1 4 4	1 3 9	1 3 1	1 2 5	1 1 10	1 1 2	1 0 6	0 11 11	0 11 3	0 10 8	0 10 0
STERN-POST Fore and aft Below	1 9 0	1 8 5	1 7 10	1 7 3	1 6 8	1 6 0	1 5 5	1 4 10	1 4 3	1 3 8	1 3 1	1 2 6
STERN-POST Fore and aft Above	1 5 0	1 4 6	1 4 0	1 3 7	1 3 1	1 2 7	1 2 2	1 1 8	1 1 2	1 0 8	1 0 3	0 11 9
TIMBERS. Floor Broad on the keel	1 3 0	1 2 4	1 1 8	1 0 11	1 0 3	0 11 7	0 11 10	0 10 3	0 9 6	0 8 10	5 8 [illegible]	[illegible] 7 6
TIMBERS. Floor Deep on the keel	1 11 0	1 9 11	1 8 11	1 7 10	1 6 10	1 5 10	1 4 9	1 3 8	1 2 8	1 1 7	1 0 6	0 11 6
TIMBERS. Floor Out and in at the head	1 3 0	1 2 4	1 1 8	1 0 11	1 0 3	0 11 7	0 10 11	0 10 3	0 9 6	0 8 10	0 8 2	0 7 6
TIMBERS. Futtocks out and in at the lower deck	1 1 0	1 0 5	0 11 10	0 11 3	0 10 8	0 10 8	0 9 5	0 8 10	0 8 3	0 7 8	0 7 1	0 6 6
TIMBERS. Top timber Broad	1 1 0	1 0 6	0 11 11	0 11 5	0 10 11	0 10 5	0 9 4	0 8 10	0 8 3	0 7 9	0 7 6	0 7 3
TIMBERS. Top timber Out and in at the lower deck ports	1 0 6	0 11 11	0 11 4	0 10 9	0 10 3	0 9 1	0 9 1	0 8 6	0 7 11	0 7 5	0 6 10	0 6 3
TIMBERS. Top timber Out and in at the head	0 10 0	0 9 6	0 9 0	0 8 7	0 8 1	0 7 7	0 7 1	0 6 8	0 6 2	0 5 8	0 5 2	0 4 9
TIMBERS. Fashion-piece Sided	1 2 6	1 1 10	1 1 2	1 0 6	0 11 10	0 11 2	0 10 6	0 9 11	0 9 3	0 8 7	0 7 11	0 7 3
TIMBERS. Fashion-piece Out and in Below	1 3 0	1 2 3	1 1 8	1 0 [illegible]	1 0 3	0 11 7	0 10 11	0 10 3	0 9 7	0 8 10	0 8 2	0 7 6
TIMBERS. Fashion-piece Out and in Aloft	1 1 0	1 0 5	0 11 10	0 11 3	0 10 0	0 10 8	0 9 5	0 8 10	0 8 3	0 7 8	0 7 1	0 6 6
TRANSOMS. Wing square	1 6 0	1 5 5	1 4 10	1 4 3	1 3 8	1 3 0	1 2 5	1 1 10	1 1 3	1 0 8	1 0 1	0 11 6
TRANSOMS. Deck Moulded	1 2 0	1 1 [illegible]	1 0 10	1 0 3	0 11 7	0 11 0	0 10 5	0 9 10	0 9 3	0 8 8	0 8 1	0 7 5
TRANSOMS. Deck Sided	1 5 6	1 4 10	1 4 2	1 3 5	1 2 9	1 2 1	1 1 5	1 1 9	1 0 0	0 11 5	0 10 8	0 10 0
TRANSOMS. second and third Moulded	1 2 0	1 1 4	1 0 8	1 0 0	0 11 4	0 10 8	0 10 0	0 9 4	0 8 8	0 8 0		
TRANSOMS. second and third Sided	1 5 0	1 4 5	1 3 11	1 3 4	1 2 9	1 2 3	1 1 8	1 1 1	1 0 7	1 0 0		
WALES. 1st and 2d thick	0 9 0	0 8 8	0 8 3	0 7 1	0 7 6	0 7 2	0 6 10	0 6 5	0 6 1	0 5 9	0 5 4	0 5 0
WALES. 1st and 2d broad	1 3 0	1 2 8	1 2 3	1 1 11	1 1 6	1 1 2	1 0 10	1 0 5	1 0 1	0 11 9	0 11 4	0 11 9
WALES. 3d and 4th thick	0 7 0	0 6 8	0 6 4	0 6 0	0 5 8	0 5 4	0 5 9	0 4 8	0 4 4	0 4 0		
WALES. 3d and 4th broad	1 1 0	1 0 8	1 0 4	1 0 0	0 11 8	0 11 4	0 11 0	0 10 8	0 10 4	0 10 0		
WALES. 5th and 6th thick	0 6 0	0 5 8	0 5 6	0 5 6	0 4 10	0 4 7	0 4 3	0 4 0				
WALES. 5th and 6th broad	1 0 0	0 11 6	0 [illegible] 0	0 10 7	0 10 1	0 9 7	0 9 2	0 8 8				

Note, The Scantlings of the Knees moulded is $\frac{2}{3}$ from the Throat.



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CHAP. III.

A Method to lay down a Seventy Gun Ship upon the Plane of Elevation.

THE Dimenſions we have given of the principal parts of a ſhip of each claſs collected from the practice of different builders, which many have ſo great a regard to, as not to vary from them in the minuteſt article, we think only to be ſo far obſerved, as they ſhall produce ſuch a form as the ſervice the ſhip is deſigned for, ſhall require, agreeable to mathematical principles.

We ſhall now illuſtrate what has been ſaid on that head by drawing a ſhip from theſe dimenſions. But it will be firſt neceſſary to obſerve, that the builders make uſe of three different planes for one ſhip; 1ſt, the plane of elevation, in which the whole length is laid down according to a ſide view; 2d, The plane of the projection, which ſome call a vertical plane of the timbers, becauſe it gives us an end view of the form of all the timbers, before the plank is put on. 3d, The horizontal plane, upon which are deſcribed all the curves that are formed by ſections of the body parallel to the horizon, which muſt be conſidered as well as thoſe vertical ſections which form the curves of the timbers. We may likewiſe form the curves of the ribbands upon this plane, which will be of great uſe in proving whether the form we give the timbers will produce a fair ſide.

It is indifferent with which of theſe we begin, though that of the elevation ſeems moſt commodious. But firſt of all it will be very proper to draw out a liſt of all the dimenſions of the veſſel we are to build, ſo that we may have a view of the whole deſign.

This ſhip then is to have two tier of guns, ſo there muſt be two decks quite fore and aft, likewiſe a quarter deck as far as the main maſt, a forecaſtle 33 feet long, and a poop to the mizen maſt.

There are to be 13 ports of a ſide on the lower deck, the guns to carry 24 lb ſhot; 14 ports on each ſide upon the upper deck, the guns to carry 18 lb ſhot; on the quarter deck 4 guns, and on the forecaſtle 2 guns of 8 lb ſhot on each ſide, and 2 of 4 lb on each ſide on the poop.

Ports

	feet	in.	l.
Ports on the lower deck fore and aft	2	10	
Distance betwixt the ports	7	9	
Aftermost port from the post	9	3	
Foremost from the stem	17	2	
Height of the sells, including the lower deck planks	2	5	
Ports up and down on the lower deck	2	7	
Distance from the upper side of the lower deck beam to the upper side of the upper deck beams	6	11	
Rising of the second deck abaft		11	
Second deck ports up and down	2	4	
Second deck ports fore and aft	2	6	
Height of the sells from the deck line	1	11	6
Distance betwixt the second deck and quarter deck from plank to plank	6	6	
Quarter deck ports up and down	1	10	
Quarter deck ports fore and aft	2		
Height of the sells	1	4	
Distance betwixt the quarter deck and poop	6	2	
Ports on the poop fore and aft	1	10	
Height of the sells	1	0	
Length from rabbit to rabbit on the gun deck	156	3	
Extreme breadth	42		
Depth in the hold below the plank	21	0	0
Rising of the lower deck abaft, not including the difference of the draught of water	2	11	6
Height of the stem	31	9	3
Height of the post	31	7	9
Rake of the stem	15	7	2
Rake of the post	3	1	5
Length by the keel	139	6	10
Depth of the keel	1	7	3
Length of the wing transom	27		
Length of the midship floor timber	21		
Rising of ditto	1	9	
Difference of the draught of water abaft more than afore	3	2	
Height of the rising line of the floor abaft	13	6	0
Height of the rising line of the floor afore	5	7	5

I would advise young beginners in the art of drawing to conform exactly to these dimensions, which we have here given for an example, and

and obſerve all the particular directions which we ſhall give in laying down a ſhip of 70 guns; for they muſt begin by making themſelves acquainted with the terms, and thereby gain a general idea of the whole deſign. After finiſhing this draught, they may then proceed to another of a different rate, and as we have given the principal dimenſions of ſeveral good ſhips, they may chuſe ſuch a one as will beſt anſwer their deſign.

Plate II. Fig. I.] 1ſt. Provide a ſcale of equal parts properly divided into feet and inches, adapted to the intended length of the draught, and draw the line A B, which make 156 feet 3 inches for the length of the gun deck, from the rabbit of the ſtem to that of the poſt.

	f.	in.	l.
To find the length on the gun deck, multiply 13, the number of ports, by 2 f. 10 in. the dimenſions of each port fore and aft, the product is	36	10	0
Again multiply 7 f. 9 in. the diſtance betwixt the ports, by 12, the number of ſpaces, the product is	93	0	0
Aftmoſt port before the poſt	9	3	0
Foremoſt abaft the ſtem	17	2	0
Length on the gun deck	156	3	0

2dly, Draw the line C D equal and parallel to A B, let 21 feet, the half of the main breadth, be the diſtance betwixt them, and erect the perpendulars C F and D Z.

3dly, Set off 3 feet 2 inches, the difference of the draught of water, from B to G, and draw the line A G, which will give the poſition of the lower ſide of the keel. From A ſet off 1 foot 7 inches 3 lines, the depth of the keel, as in the table of ſcantlings, to K, and draw the line K I parallel to A G, which will be the upper ſide of the keel.

4thly, Set off 1 foot 3 inches 3 lines, the breadth of the ſtem, from G to M, and draw the dotted line M N parallel to G Z. From G ſet off 15 feet 7 inches 2 lines, the rake of the ſtem, to O.

5thly, Set up 31 feet 9 inches 3 lines, the height of the ſtem from G to P. With the radius I P deſcribe the arch P O, which will be the fore ſide of the ſtem, and from the ſame center deſcribe another arch within the former, which will give the inſide of the ſtem, and another arch for the rabbit may be deſcribed four inches before the inſide of the ſtem.

6thly, Set up 25 feet 1 inch from K to L for the height of the gun deck abaſt, and 21 feet 6 inches from I to *e*, for the height afore.

7thly, Set up 2 feet 5 inches, the height of the port-ſells from L to *a*, which will give the upper ſide of the wing tranſom; from which ſet up

2 feet 7 inches, the height of the ports; also 1 foot for the depth, and 6 inches 9 lines for the round of the helm port transom, to the point F, which will be the height of the post; so K F will be 31 feet 7 inches 9 lines. From K set off 3 feet 1 inch 5 lines to *f*, for the rake of the post, and draw the line F *f* for the aft side of the post. From *f* to *b* set off the depth of the keel, and draw the line *b d* for the fore side of the post, making F *d* $\frac{1}{4}$ of *f b*, so shall *f* O be the whole length of the keel.

The builders are very much divided about assigning a proper place for the midship frame, for which the following method may be used.

Divide the line C D into two equal parts, then take 5 feet 6 inches 10 lines, that is $\frac{1}{27}$ part of 156 feet 3 inches, the length of the gun deck: Set of this before the middle of the line C D, which will give the point F, the station of the midship frame. Set up 21 feet from F to Z, which will give the height of the gun deck at the midship frame. From the point Z set off 2 feet 7 inches 6 lines (the $\frac{1}{8}$ of the height of the gun deck at the midship frame,) through which point draw a line V T, parallel to C D, which will be the load-water line. Through the point F draw the line G *g*, parallel and equal to the load-water line, which will shew how much water the ship will draw abaft more than afore.

One of the frames is placed pretty near the chess tree, which is called the loof frame; to find its place, from the point D set off $\frac{1}{4}$ of the line D C, and there draw a dotted line perpendicular to A B. Again divide the line F G into nine equal parts, and draw eight lines perpendicular to A B, which will station eight frames in the fore-body besides that of the loof.

There is in the after-body a frame to balance that of the loof in the fore-body; these two are of equal breadth in some points, and this will occasion the center of gravity of that part contained betwixt these two frames to be near the plane of the midship frame, which will keep the fore part and after part upon a balance. It must be as far abaft the middle of the line C D as that of the loof is before it.

The frames in the after-body are the same distance from one another as they are in the fore, which will occasion one more abaft than before; so there are nine abaft, besides that of the balance.

We shall in the next place lay down the deck lines, and first for the lower deck draw a fair curve through the points L Z *e*, and parallel to it draw another curve for the port-sells, which are 2 feet 5 inches above the deck line.

The

The aftermost port is 9 feet 3 inches before the post, which set off to *n*, and the ports are 2 feet 10 inches fore and aft; which set off from *u* to *x*, the distance betwixt the ports is 7 feet 9 inches, which set off from *x* to Y for the aft side of the second port; from Y again set off 2 feet 10 inches, which will give the foreside of the next. Proceed in the same manner till all the ports are spaced; so shall the foremost port be 17 feet 2 inches abaft the rabbit of the stem. The height of the ports is 2 feet 7 inches, which set up from *u*; draw a curve parallel to the deck line, which will give the upper part of all the ports; after which these two lines may be wiped off the draught, which must be therefore drawn with a black lead pencil, and only the ports inked in.

Draw a line for the upper deck, which is 6 feet 11 inches above the lower from the midship frame forward, and 6 inches more abaft. We may then draw a line for the port-sells, and one for their height, parallel to the deck line, and space the ports so that they may be exactly over the middle of the distance betwixt the lower deck ports.

Before we can set of the height of the quarter deck we must find the true place of the main mast. The general rule is to take 4 lines for every foot the gun deck is in length, and set it off abaft the middle, which will give the foreside of the mast, now the length 156 feet 3 inches × 4 lines = 625 = 4 feet 4 inches 1 line, which set off abaft the middle of the line C D, and there erect a line perpendicular to the water-line, which will be the fore side of the mast; and parallel to it draw a line for the middle, and one for the aft side of the mast, the diameter of which is 35 inches. Set off 6 feet 6 inches on the aft side of the main mast, for the height of the quarter deck afore, and 6 feet 10 inches for the height abaft; and draw a line nearly parallel to that of the upper deck, which will be the line for the quarter deck. We may then space the ports, so that they may be exactly over those of the lower deck. The forecastle is 6 feet 6 inches high, at which distance draw a line parallel to the upper deck line, which will give the line for the forecastle deck. As to the length of this deck, it ends forward at the beak head, and is carried aft discretionally, observing to leave room for the capstan bars. In spacing the ports upon the forecastle, care must be taken that none be opposite to the fore mast. Now to find the center of this mast, take 15 feet 7 inches 2 lines, the tenth part of the whole length, which set off from the rabbit of the stem upon the lower deck abaft, from which point set off 32 inches and 1 line, being the diameter of the mast; through the middle of this draw a perpendicular line, as in the plate. The boltsprit generally makes an angle of 34 or 35 degrees with the load-water line.

 The

The poop is pretty near parallel to the quarter deck; the diſtance betwixt them forward is 6 feet, and abaft 6 feet 3 inches. It ends about 18 inches before the mizen maſt, the aft ſide of which is $\frac{1}{7}$ of the main breadth before the rabbit of the poſt upon the gun deck.

The counter is generally an arch paſſing from the upper ſide of the wing-tranſom to the lower ſide of the beam of the ſecond deck. The rake of the lower counter is $\frac{3}{4}$ of an inch for every foot of the main breadth. The rake of the ſecond counter is $\frac{3}{4}$ of the lower; its height above the deck is 3 feet 5 inches. The hollow of the counters is altogether arbitrary, inſomuch that ſome give none to the lower. The upright of the ſtern rakes 2 inches in a foot, as in the plate.

The beauty of a ſhip depends much upon giving the wales a proper hanging; for by them the ſheer and drift rails are regulated, being all nearly parallel to one another, though they generally riſe a little more abaft on account of the accommodations for the officers. It is this which makes a ſhip look airy and graceful in the water. There is no certain rule for laying them down; this is left entirely to the fancy and taſte of the artiſt; but in placing the wales great care muſt be taken that they be wounded as little as poſſible by the ports; the foremoſt port on the gun deck muſt be 1 $\frac{1}{2}$ or 2 inches above, and the third port from abaft juſt touch the upper ſide of the upper ſtrake of the main wales. The lower edge of the lower ſtrake may glance with the edge of the water when loaded. There are two ſtrakes of wales, and one ſtrake between them of 15 inches broad each. The range of the deck ſhould be conſidered in placing the wales, ſo that the ſcuppers may be in the ſtrake betwixt the wales. The like caution muſt be uſed for the channel wales as may be ſeen in the plate, where they are all laid down, together with the ſheer and drift rails; the rails, cheeks, and knee of the head are likewiſe laid down in the plate, and being for an ornament to the ſhip, are left to the fancy and taſte of the builder. Though the knee may help a ſhip to hold a good wind, the fore part of it is generally one twelfth part of the length before the ſtem.

CHAP.

CHAP. IV.

To lay down the Frames upon the Plane of Projection.

HAVING thus explained all that is neceſſary to be delineated upon the plane of elevation, the next thing to be determined is the different breadths of the ſhip at any aſſigned points of the length, whereby we ſhall gain the forms of all the planes that are made by ſections, perpendicular to the load-water line. The timbers that compoſe the body of a ſhip are ſuppoſed to have their planes in that poſition, and may be all delineated upon the plane of the projection; but as both ſides of a ſhip are exactly the ſame, it will ſuffice to lay down the half of each, thoſe of the fore-body on the right, and thoſe of the after-body on the left hand. And whereas theſe planes diminiſh afore and aft, the planes of all the frames may be all delineated upon the plane of the midſhip one, which may be called the maſter-frame. The firſt thing then neceſſary to be known, is how to form this frame.

The mid-ſhip frame is that which is at the broadeſt part of the ſhip. The builders differ about the form of this frame, but there are ſeveral preliminary operations which are neceſſary to be obſerved in all the different methods uſed in forming it.

Preliminary Operations for forming the Midſhip Frame.

Plate III, *Fig.* I. *and* II.] 1ſt. Draw the line AB to repreſent the upper ſide of the keel; it muſt be at leaſt as long as the ſhip is broad. This line our author calls the line of *aculement*, becauſe upon it the aculement of the midſhip floor timber terminates.

2dly, Draw the line CD parallel and equal to AB, ſo that AC and BD may be equal to the riſing of the midſhip floor timber. This line may be called the riſing line, becauſe it limits the height of the ends of the midſhip floor timber above the keel.

3dly, Draw the line GH, for the height of the lower deck, parallel to the former; and below this, draw a line to repreſent the load-water line, taking its diſtance below the deck line from the plane of elevation at the midſhip frame. Draw alſo the lines IK and LM, the one for the ſecond deck, and the other for the ſheer rail or top of the ſide in midſhips. The height of both are to be taken from the plane of elevation.

4thly,

4thly, Draw the line N O perpendicular to A B; this is called the middle line, and represents the middle line of the stem and post, dividing the whole ship into two equal parts; and parallel to N O draw the lines A L and B M, to limit the breadth; also a line for half the thickness of the stem, and one for half the thickness of the post. Draw the lines *z x* parallel to N O, dividing the lines O A and O B into two equal parts. Draw also the diagonal G B. These lines being drawn, we may proceed to form the midship frame by some of the following methods.

METHOD I.

To form a Midship Frame, that shall be neither too sharp nor too flat.

Plate III. *Fig.* I.] 1st, Divide the line *a x*, which marks the head of the floor timber into three equal parts; set off one from *a* to *h*.

2d, Divide the line *d* B, the distance betwixt the load-water line and the upper side of the keel, into seven equal parts; set off one of these from *d* to *e*, and from *e* to *m*, and draw the diagonal *a* V, which divide into two equal parts in the point *n*. *Note, the diagonal, a* V, *is wiped out, after finding the point n.*

3d. Describe an arch of a circle to pass through the points *h* and *e*; make the radius the whole length and half the length of the line B *e*, so the center A may be found by describing an arch with that radius from *e*, and one from *h* to intersect one another in A, we shall only make use of that part of this arch betwixt *l* and *m*. Now, to find the other arches *m d*, *l a*, *a n*, *n* V, it must be observed, that, in order to reconcile two arches, so as to make a fair curve, a strait line must pass through the centers of both, and through the points where they unite or touch one another; draw therefore the lines A *m* and A *l*, so shall *k* be the center of the arch *m d*, and *o* the center of the arch *l a*. Again, through the center *o* draw the line *a o*, produce it to P, which will be the center of the arch *a n*. Lastly, from P thro' *n* draw the line P *s*, *s* will be the center of the inverted arch *n* V. *Note, the center s will be without the Plate.*

4th. To form the top timber, set back the tenth part of the half breadth from K to S, upon the line of the second deck; describe an arch of a circle thro' the points *d* and S, taking $\frac{2}{3}$ of the whole breadth for the radius: Again, from the point M, upon the line L M, set back the fifth part of the whole breadth to *l*. Describe an arch of a circle thro' the points S and *l*, taking the diagonal G B for the radius. As this arch is inverted in respect of the arch *d* S, the center will be without the figure. This compleats the form of half the midship frame, and by the same operations we may find the other half.

It must be observed, that there is no regard had to the round of the beam in setting off the deck line or depth of the hold. ME-

METHOD II.

To describe a Midship Frame of a circular Floor.

Plate III. *Fig.* II.] From the center G, the point where the middle line intersects the deck line, making the half breadth the radius, describe the arch *b*, G, *c*, O: Let *d* be the head of the floor timber, and *d x* the rising. Assume the point *f*, according to what round you propose to give to the second futtock, and describe the arch *d f*; the center may be found as directed in the preceding method. Divide the arch *c* O into three equal parts; set off one from *c* to *g*, and from the center *b*, describe the arch *d g*; there remains only the inverted arch *g* Y to be described; the center may be found as before directed.

METHOD III.

To draw a Midship Frame which shall be full.

Plate III. *Fig.* III.] 1st. Draw the rising and deck lines as before; let *b x* be the rising.

2d. Make *d b* the side of the square *d b a c* equal to C *b* the $\frac{1}{4}$ of the breadth.

3d. Inscribe the two quadrants *c e b*, and *c f b*, into the square.

4th. Divide the side *c a* into a certain number of equal parts in the points O, N, M, L *a*; draw the lines *i* L, *h* M, &c. perpendicular to *a c*.

5. Divide the line C G, the depth of the hold, after deducting the rising, into the same number of equal parts in the points E, F, I, K, and make the lines E *p*, F *q*, I *r*, K *s*, in the frame, equal to the lines O *t*, N *n*, M *e*, L *m* in the square, describe a curve through the points G, *p*, *q*, *r*, *s*, *b*, and the remaining part of the frame may be described by the preceding methods.

METHOD IV.

To describe a Midship Frame for a very sharp Ship.

Plate III. *Fig.* IV.] Let the length of the floor timber be half the breadth as before, and the rising one fifth or one sixth of the whole length of the floor timber; lay this off from *x* to E, and describe a parabola through the points G, P, Q, E, of which the point G is the vertex, and G C the axis. This method is extracted from M. *Bouguer*. The parabola may be formed by the following method: 1. Through the point E draw the line T *x* perpendicular to G C, and the line *d* E perpendicular to A G, and produce

produce the line C G to D. 2dly, Upon the line C D find the center of a semicircle that shall pass through the points T, *d*, and D, so shall G D be the parameter of the parabola, by which we may find any number of points through which the curve must pass: For instance, suppose it were required to find a point in the perpendicular X P, through which the curve must pass; upon the line G D find the center of a semicircle which shall pass through the points D and X; this will intersect the line A G in *b*, make *b* P equal and parallel to G X, so shall P be the point required; in like manner, the points *a* Q *f* may be found. The remainder of the curve from E to *y* will be composed of two arches, the one to reconcile with the parabola in the point E, and the other inverted to pass through the point *y*; the center of which may be found by any of the preceding methods. In order to find the center of that which joins with the parabola, make T R equal to half the parameter G D, and draw the line E R, upon which find a point S for the center of the arch.

We might shew a great many more methods of describing this midship frame. It is very true, that great care ought to be had in forming this frame, because upon it chiefly depends the form of all the other timbers; I say chiefly, but not altogether; for two ships may be similar as to their midship frames, and yet very different afore and abaft; and though the artists should make themselves acquainted with all the different ways of forming this frame, I should recommend that method to them which is the simplest, and which gives them the most liberty to vary the form of it, according to every one's particular taste or fancy; and it is very possible there may be several other methods as easy and plain as those we have described. This frame being once formed, we may form all the rest upon the same plane. We shall, in the next place, shew the different methods used by the builders for that purpose.

The ancient builders, not being acquainted with the methods of laying down their designs in a draught, found out a mechanic way of doing this, only by help of the midship frame, which they might have formed by some of the preceding methods, or any other contrivance of their own; and though this method is defective in several points, yet as it is an ingenious contrivance, we shall give it a place here.

METHOD I.

Of forming the Timbers by a Mould made to the Midship Frame; a rising Staff and overcast Staff.

Plate III. *Fig.* VII.] 1st. Having formed the midship frame, and set off its scantlings, make a mould to fit both outside and inside, which may be called the bend mould.

2d.

2d. Draw the line Z *x* to limit the head of the floor timber at *d*; let *d u* be the riſing, and draw the line *a u*; let *t* be the height of the riſing line abaft, and draw the line *d t* to repreſent the floor heads, or floor ribband. Set off *d x* from *d* to H; and from *e*, the head of the firſt futtock, to 6, and divide each in ſix equal parts, being the number of frames from midſhips to the balance frame.

3d. Divide the line *a u* into five equal parts, and ſet off two of them from *a* to S; divide the line *a* S into the ſame proportion, that the part A 6 of the baſe A C of the right angled triangle (*Fig.* 5.) is divided into, and transfer theſe diviſions to the bend mould, and let them be numbered 0, 1, 2, 3, 4, 5, 6, which points will give the narrowing of the floor, as we ſhall ſhew, after conſtructing the triangle. We ſhall only remark, that the line *a* S, which is $\frac{2}{5}$ of *a u*, is nearly the difference betwixt half the length of the midſhip floor timber, and half the length of the floor timber at the balance frame. But as this appears to be too much, we may take $\frac{2}{6}$ as in the figure, or any other quantity which ſhall be thought moſt convenient.

To conſtruct the Triangle, Fig. 5.

Upon the line A C, drawn at pleaſure, ſet off any diſtance from A to 1, and double that diſtance from 1 to 2, treble from 2 to 3, and ſo on in the ſame progreſſion till we have as many diviſions on the line A C as we propoſe to have frames abaft the midſhip. Erect a perpendicular at A, which may be produced at pleaſure, and from any point B draw lines to all the diviſions of the baſe A C. Obſerve, that though in the triangle we have drawn a line for every frame to the faſhion piece, we ſhall only make uſe of ſix, there being ſo many to the balance frame. The triangle being thus conſtructed, apply the line *a* S to it, in ſuch a manner, that it may be parallel to A C, and be contained betwixt the lines B A and B 6, the lines drawn from the point B to the points 1, 2, &c. will divide it into the required proportion.

To conſtruct the Riſing Staff, Fig. 5.

This ſtaff K L may be of the ſame breadth with the keel, and a little longer than *a t*, the height of the riſing of the floor. In order to graduate that ſtaff, ſet off *x u*, the riſing of the midſhip floor from K to *o*, and make *o* L equal to *a t*; apply the line *o* L to the triangle, ſo that it may be parallel to the baſe, and contained betwixt the lines A B and B C the lines from the point B to the ſeveral points in the baſe will divide it into the required proportion, which will give the riſing of the floor.

Note, Our author calls x u *the acculement, and* u d *the riſing; the line* u a *will paſs through the point where the inverted arch joins the floor ſweep.*

To conſtruct the over caſt Staff, Fig. 5.

That we may have a clear underſtanding of what is meant by *over-caſt*, it will be proper to obſerve, that in forming the frames by the bend mould, when it is ſet to the narrowing of the floor, the head of the mould will come too far in at the deck; the mould muſt therefore be moved round upon the point which repreſents the floor ribband, till the head goes out to the proper breadth; this will occaſion the lower part of the mould to riſe a certain quantity, which is called the over-caſt. In order to graduate this ſtaff we muſt determine the difference betwixt the main breadth at the midſhip frame, and at the balance frame, which ſuppoſe DF, let this be placed parallel to the baſe, and contained betwixt the line BA and B 6; ſo ſhall the lines B 6, B 5, *&c.* divide it into the required proportion.

Theſe are the inſtruments that are neceſſary for forming the after frames, thoſe for the fore part are conſtructed in the ſame manner, only the graduations for theſe are but half the graduations of the former, for which reaſon there muſt be another bend mould graduated for the forebody.

Now, in order to form the frames by theſe inſtruments, place the bend mould upon the riſing ſtaff in ſuch a manner that the middle line of the ſtaff produced may paſs through the narrowing of the floor upon the bend mould, expreſſed by the diviſion correſponding to the frame to be formed; ſuppoſe frame 6, (*Fig.* 7.) the lower or ſtrait part of it expreſſed by the dotted line in the figure being applied to the riſing ſtaff, till the middle line B *a* paſs through the diviſion 6 on the bend mould: mark by the edge of the riſing ſtaff the point 6, which expreſſes the riſing of the floor at that frame. Set up the over caſt (expreſſed by the ſpace contained betwixt the points 5 and 6 upon the over caſt ſtaff) from the lower part of the bend mould to the point 6 upon the line B *a*; then keeping the point *d* immoveable, turn the bend mould upon this point till the lower part riſe to the over caſt at the point 6, upon the line B *a*, and when in this poſition we may deſcribe the curve to the floor head, and then invert the bend mould, and placing the point 6 (betwixt *d* and H) to the point ſet off before to expreſs the riſing, turn the mould

till

till the ſtrait part touch the curve before deſcribed, and then draw the lower part, which compleats the frame.

This is the method that is uſed when they mould the timbers, and it may likewiſe be uſed to lay them down upon a draught; for if the line *a u* of the bend mould (*Fig.* 8.) be laid upon the line A V, we may, when in that poſition, deſcribe the midſhip frame from the point *d* to the point *x*. In like manner we may deſcribe all the reſt of the frames, by giving each its proper over-caſt and riſing; as for inſtance, if it were required to deſcribe frame 6, take the riſing K 6 upon the riſing ſtaff, and ſet it off from the point B to the point *a* upon the line B G, and draw a line through the point *a* parallel to A V, upon which laying the bend mould in ſuch a manner that the point 6, which expreſſes the narrowing of the floor, ſhall be upon the point *a*; then will the point *d* be upon the point R: Set up the proper over-caſt from *a* to 6, and keeping the point *d* immoveable, puſh up the bend-mould, which at firſt was placed at the point *a*, till it be raiſed to the point 6, which will throw out the point *x* to the proper breadth at the deck. But becauſe the deck is higher at timber 6 than at the midſhip frame. Take the diſtance betwixt *e* and 6, at the head of the futtock on the bend mould, and ſet it up from *x* to 6, and then inverting the bend mould, ſo that the point 6 betwixt *d* and H be at the point X, and the ſtrait part of the mould touch the curve before deſcribed: we may then deſcribe the lower part to the point X, which compleats the whole frame. The timbers for the fore body may be deſcribed by the ſame proceſs as thoſe of the after body, only making uſe of the bend mould, riſing, and overcaſt ſtaff, graduated for that purpoſe; but, as we obſerved before, we cannot lay down any timbers by this method, but thoſe betwixt the midſhip and ballance frame.

The builders finding how very advantageous it would be for them to form all the timbers upon the plane of the projection, becauſe they could then at one view ſee how they would compare one with another, have tried ſeveral expedients to perform this, of which I might inſtance ten or twelve, but ſhall content myſelf with explaining three, which may be ſufficient for thoſe purpoſes, in order to which I ſhall firſt ſhew another method of forming the midſhip frame, different from thoſe we have ſhewn before.

Plate III. *Fig.* 6. 1ſt. Draw the riſing deck, and load-water lines, and ſet off the length of the floor timber as before.

2d. Take one fourth of the length of the floor timber, and ſet it off from O to *d*, upon which erect the perpendicular *d c*, and divide it into two equal parts in the point *e*.

3d. Defcribe an arch through the point *a*, the head of the floor timber, and the point *e*, taking for the radius the diftance from the upper edge of the keel to the port-fells, or a little more or lefs, according to what round you propofe to the floor head. This determines the rifing of the floor timber, and with the radius O *l*, half the length of the floor timber, defcribe the arch *e* Y, which determines the *aculement* of the floor timber.

4th. At the point *l*, the middle of the line A O, erect the perpendicular *l m*; and at the point *n*, the middle of the line A *l*, erect the perpendicular *n o*; erect alfo the perpendicular *p q* at the middle of the line A *n*; and another *r s*, at the middle of the line A *p*; and laftly, another *t u*, at the middle of the line A *r*.

5th. Take the diftance *l n*, which fet off on the line *n o* from *n* to *z*; and on the line *p q*, from *p* to *g*; then taking the diftance from *a* to *g*, fet that off from *p* to *y*; again take the diftance *p y*, which fet off from *r* to *b*, and the diftance *b a* from *r* to F; and laftly take the diftance *r* F, which fet off from *t* to E, and then the diftance E *a* from *t* to X, a curve paffing through the point *a*, *z*, *y*, F, X, T, will form the midfhip frame under water. We may then fet off half the thicknefs of the poft and ftem on each fide off the middle line, and form the reft of the timbers; thofe for the fore body on the right, and for the after body to the left of the middle line.

Plate II. 1ft. To lay down the poft upon the plane of projection, take the difference of the draught of water abaft more than in midfhips, as marked on the plane of elevation (*Fig.* 2.) fet off this from F to *e*, (*Fig.* 3.) and draw the line *d e* parallel to A B; take alfo K F, the height from the plane of elevation, which fet off from *e* to *r*, fo fhall the point *r* be the head of the poft.

2d, To lay down the wing tranfom, take its height from the plane of elevation, which fet up on the plane of projection to *f*, and draw the line *g f* perpendicular to the middle line, fo *g f* reprefents the upper fide of the wing tranfom, without regarding the round up or the round aft. Take alfo the height of the rifing line upon the poft from the plane of elevation, which fet off from *e* to G.

3d. To form the fafhion piece; take upon the plane of the projection *n* G the height of the load-water line, above the rifing line upon the poft, which fet off from *n* to *o* upon the water line; take alfo G P, the diftance betwixt the rifing line and lower deck, which fet off from P to *q* upon the deck line, and defcribe a circle through the points *f*, *q*, *o*. There is a problem in geometry to find the center of this arch. *Note*, the point *q* may be taken further out or in, as you defign a lank or full fafhion piece.

Laftly,

Laſtly, deſcribe the arch *o* G; the radius of this arch may be the main half breadth; ſo ſhall *f*, *q*, *o*, G, be the form of the faſhion-piece, which may be varied according to the fancy of the artiſt, by altering the centers.

Having thus formed the midſhip and after-frames, we ſhall, in the next place, ſhew how to ſpace the ribband lines, which are repreſented by the diagonals in the figure; but it will be proper to remark, that the ribbands are thin narrow planks, which are made ſo, that they may eaſily be bent to the timbers. That which is nailed to the poſt at the height of the riſing line, and to the midſhip frame, at the end of the riſing of the floor timbers, is called the floor ribband. That which anſwers to the wing tranſom and to the height of the lower deck, on the midſhip frame, is called the breadth ribband; all the reſt betwixt theſe two are called intermediates.

From the point H draw the line H G for the floor ribband, and from the point T draw the curve T, E, *q*, *p* for the breadth ribband, and draw the two intermediates betwixt them, ſo that by them the curve of the midſhip frame and faſhion piece may be divided into three equal parts.

Now, it is very plain, that if the ribbands had a proper form, and nail'd at the proper heights and poſitions, they would compoſe a kind of a model, by which the circular form of every timber might eaſily be diſcovered; but as we have only the extreme points of each given, we cannot from thence form ſuch a curve as ſhall be neceſſary. We muſt therefore find a method to form ſome intermediate timbers betwixt the midſhip and after one, and thereby form the ribbands ſo that they ſhall make fair curves. There are ſome preliminary operations which are neceſſary towards performing this.

1ſt. *To conſtruct an equilateral Triangle for the Progreſſion of the Frames in the After-Body.*

Plate IV. *Fig.* I. From the point M ſet off any diſtance to 1, upon any ſtrait line, and from 1 to 2 treble that diſtance, from 2 to 3 five times that diſtance, from 3 to 4 ſeven times that diſtance, and proceed in that progreſſion, increaſing the ſpaces betwixt the figures by equal differences, *viz.* double the diſtance betwixt M and 1, till we have as many diviſions leſs one as there are frames betwixt the midſhip and poſt, including that of the midſhip and poſt; and becauſe there are nine frames the line muſt conſiſt of ten diviſions, from the point M to the point E. Let them be numbered 1, 2, 3, *&c.* make M E the baſe of an equilateral triangle S M E, and draw the lines S 1, S 2, *&c.* obſerving to produce them all till the diſtance betwixt the lines S E and S 9, upon a line parallel to the baſe, be at leaſt equal to the diſtance betwixt the frames in the plane

of

of elevation. The line S M represents the midship frame, and the line S E, the post, and the nine intermediates represent the nine frames betwixt the midship and post.

In order to give us a clear understanding of the use of this triangle, it will be necessary to remark, that the midship frame being that which incloseth the greatest space, and the aftermost that which incloseth the least, it will follow, that the intermediate frames will partake of the form of each, but mostly of that to which they are nearest; yet they will still retain a little of the form of each. Hence, when the intermediate frames are all formed, their curves will divide all the diagonals, drawn in the plane of projection, into as many parts as there are frames; and all the methods the builders have invented serve only to divide them into such a proportion as shall produce the fairest curves.

Now, if the proportion pitched upon for that purpose, be as 1, 3, 5, 7, 9, *&c.* then they must all be divided into the same proportions as the base of the triangle is divided into; and this may be performed very readily, only by taking the length of each diagonal from the plane of the projection, and applying it to the triangle in such a manner that it shall become the base of an equilateral triangle; as for instance, to divide the first intermediate diagonal, take the length of it in the plane of projection, (*Plate* II. *Fig.* 3.) and set it off from the point S to *m* and *k* on the sides of the triangle S M and S E; and draw the line *m k*, which being parallel to the base of the triangle, will be divided into the same proportion. In like manner, all the rest of the diagonals may be divided; but as the builders are not agreed as to the precise form of a ship's bottom, some chuse to divide the base of the triangle into another proportion; others again, in applying the diagonals to the triangle, give them different inclinations to the line M S. It would be very proper to try several of these methods, by which means we might discover which would be most convenient; and after all the diagonals are divided into as many points as there are frames, curves passing through these points will determine the form of all the frames from the midship to the post. It only remains to shew how to end each frame upon the post. It was before observed, that the keel is not parallel to the surface of the water, so that it will be very easy to conceive that the height of each frame, taken from the upper side of the keel, upon a perpendicular to the surface of the water, will always increase, the nearer the frame is to the stern post. Now, *g* K is what the keel is deeper abaft than at the midship frame; and to find how much any frame abaft exceeds that of the midship, suppose the first; take the distance betwixt the line *g* G and K I at that frame, from the plane of of elevation, (*Plate* II.) which set off from F towards *d*, (*Fig*. 3.) and at that point draw a line parallel to *d e*, which will be the first frame upon the keel. In like manner we may draw lines parallel to *d e*, for all the rest, as in the figure, which will determine their heights from the upper side of the keel to the surface of the water.

It must be observed, that the diagonals in the plane of the projection, which end on the fashion piece, must likewise end on the fashion piece on the plane of elevation; we must therefore draw the fashion piece on the plane of elevation. Thus, take the distance of the point G, in the plane of the projection, from the upper side of the keel, which set off upon the stern post in the plane of elevation to the point *b*; through *n*, the rabbit of the wing transom, draw the strait line *b* M, which will represent the fashion piece on the plane of elevation. Now, as only the lowest diagonal ends upon the post, in the plane of projection, which in the plane of elevation ends at *b*, so the other diagonals that end upon the fashion piece, must likewise end on the fashion piece in the plane of elevation. Their height must therefore be transferred from the plane of the projection to that of the elevation; so the second diagonal will end at the point P, upon the fashion piece in the plane of elevation. In like manner all the rest may be transferred to the plane of elevation; and as the line that represents the fashion piece upon the plane of elevation rakes aft, this will occasion the line P S, which is perpendicular to the line that represents frame 9, to exceed the line *b* M. In the triangle, the line S M represents the midship frame, and the line S E the post; that is, if the point where the ribband ends on the post, be equally distant from frame 9, that frame 9 is from frame 8. Now, as M *b* is longer than M L, we must draw the line S D without the triangle, which is to be used instead of the line S E, when we come to apply the diagonal H G to the triangle; for the point H must touch the line S M, and the point G the line S E. To find the point D, take M L from the plane of elevation, and apply it to the triangle, so that B C shall be equal to it, and parallel to M E; it must also be contained betwixt the line S 9 and S E. Then take *b* M, and set it off from B, which will give the point D. In like manner the line S F must be used, when we divide the diagonal M K; and to find the point F, set off P S, in the plane of elevation, from B to F in the triangle; and draw the line S F. In the same manner there must be lines drawn for every diagonal without the line S E; so the line S E is not used in dividing the diagonals. Let it be further observed, that in applying each diagonal to the triangle, it must not only be contained betwixt the line S M, and the line corresponding to the diagonal, which is to be divided, but it must likewise form a certain angle with the line M S, [*Plate* IV. *Fig*. 1.]

that

that is, with that part of it which is intercepted betwixt the diagonal and the point S. Thefe which appear to me to be propereft for that purpofe are as follows: The firft diagonal to make an angle of 60 degrees; the fecond 62½, the third 68, the fourth 86, the fifth 65, the fixth 60 degrees; but the artifts vary thefe angles according to the form they defign to give to the timbers; nay, fome draw them always parallel to the bafe of the triangle.

Our author then proceeds to the forebody, and forms a triangle, the bafe of which he divides in the fame manner as that already defcribed, by which he divides each diagonal. He likewife fhews how to fpace the diagonals upon the ftem; but as the artifts leave us fo much undetermined as to the angles that each diagonal is to make with the line S M, *when they are applied to the triangle, it will be very difficult to apply this method to practice. So we prefume it will be needlefs to fay any more on that head; judging what has been already faid fufficient to give our readers an idea of the principles on which the method is grounded; we fhall proceed therefore to the next method he propofes.*

To form the Timbers by a Quarter of a Circle. Plate IV. Fig. 2, 3.

1ft. Form the midfhip frame, the fafhion piece, the foremoft timber, alfo the two balance frames, by fome of the preceding methods. *Note, Thofe who make ufe of the following method of forming the reft of the timbers, are fuppofed to be previoufly acquainted with the manner of forming the midfhip frame,* &c.

2d. Space all the diagonals for the ribbands as directed in the preceding method.

3d. From the center A, with any radius, defcribe a quarter of a circle, and divide it into fo many equal parts, that there may be a point for each timber to be formed, and draw the radii A 1, A 2, *&c.* to A 9, fo we fhall have one for each frame.

4th. Take *a b*, the firft diagonal, which fet off from the point A upon the line A C, to 1.

5th. Take *a c*, the diftance upon the lower ribband, betwixt the poft and balance frame, which in the plane of projection is the 6th frame, fet off this diftance upon a perpendicular erected upon the line A B, to interfect the radius A 6, in fuch a manner that the perpendicular G 1 fhall be equal to *a c*.

6th. Produce the line C A to F, and upon this line find a point, which fhall be the center of a circle whofe circumference fhall pafs through the point 1, before marked upon the line A C, and the point 1, now marked upon the radius A 6; defcribe the arch through thefe two points to the point 1 on the line A B.

7th.

7th. Let fall perpendiculars to the line A B from the points where the arch 1, 1, 1, interſects the ſeveral radii. Transfer theſe perpendiculars to the line *a b*, which will divide the lower diagonal into the points through which the curves of the frames muſt paſs. *Note, the perpendiculars are not drawn, to avoid confuſion.*

After the ſame manner all the other diagonals are graduated, firſt by taking the whole length of each diagonal, and ſetting them up on the line A C, from the point A to the points 5, 4, 3, 1, 2, and ſecondly, by taking the ſeveral diſtances upon each diagonal intercepted betwixt the after frame and the balance frame, and applying them ſeverally to the radius A 6, in ſuch a manner that they ſhall be contained betwixt the radius A 6 and the line A B, upon the perpendiculars let fall from the points 5, 4, 3, 1, 2. And, thirdly, by deſcribing arches through the points in the line A C, to paſs through the points of the ſame number upon the radius A 6, whoſe centers are in the line A F; the arches to be produced to interſect the line A B in the points 5, 4, 3, 1, 2, will interſect all the radii; the perpendiculars let fall from the interſections of the radii with the arch correſponding to each diagonal, will divide that diagonal into the points through which the curves of the frames muſt paſs.

The diagonals for forming the frames in the fore body are divided into the points through which the curves muſt paſs by the ſame operations, only obſerving that frame 4 is the ballance frame for the fore body.

CHAP. V.

Of the Projections on the horizontal Planes, and of the Water and Ribband Lines on the Plane of Elevation, and that of the Projection.

WATER Lines are deſcribed upon a ſhip's bottom by the ſurface of the water into which ſhe ſwims; that which determines how much is under water when ſhe is loaded is called the load-water line. Now it is plain, that if a ſhip is lightened, ſhe will riſe higher out of the water; and if ſhe be lightened ſo as to riſe equally afore and abaft, the ſurface of the water will then form another water-line parallel to the load-water-line. Again, if the ſhip is lightened more, ſhe will ſtill riſe higher; and if the ſame difference ſtill continues betwixt the draught of water abaft and afore, we ſhall have another water line parallel to the two former;

ſo that by this means we may deſcribe as many water lines as we pleaſe, all parallel to one another.

In order to form an idea how theſe lines are repreſented on the different planes, let us ſuppoſe a ſhip upon the ſtocks upon a level ground, and her keel in the ſame poſition, with reſpect to the horizon, that it is to be in the water when loaded; we may then deſcribe ſeveral black lines upon the ſhip's bottom, which may be whitened for that purpoſe, all parallel to the horizon: Theſe will all be water lines.

Now, if a ſpectator be removed at any conſiderable diſtance from the ſhip upon a line in the ſame direction with the keel, all theſe black lines, which were drawn npon the ſhip's bottom, parallel to the horizon, and which are actually curves, will appear to him all ſtrait lines, becauſe he ſees them all upon a plane formed by a ſection paſſing through the midſhip frame perpendicular to the keel. Hence the water lines will be repreſented by ſtrait lines upon the plane of the projection.

Again, if a ſpectator is removed at any conſiderable diſtance from the ſhip upon a line perpendicular to the keel, ſo as to ſee the whole length of the ſhip at one view, the water lines will then appear to him ſtrait lines, becauſe he ſees them upon a plane erected perpendicular to the horizon upon the middle line of the keel. Hence the water lines will be repreſented by ſtrait lines upon the plane of elevation.

But if the ſpectator be ſuppoſed to be placed underneath the middle of the ſhip, at any conſiderable depth, in a line perpendicular to the level ground, he will then, viewing the ſhip's bottom upwards, diſcover the curvings of all the water lines. Theſe curves are all projected upon a plane, which we muſt imagine to be formed by a ſection of the ſhip through the load-water line, and we are now to ſhew how theſe are formed.

To form the Water Lines upon the Horizontal Plane.

Let the water lines to be formed be repreſented in the plane of the projection by ſtrait lines, all parallel to one another. Theſe will be repreſented by the ſtrait lines in the plane of elevation. Suppoſe *q r*, *s t*, *b x*, and T V, all parallel to one another, and the ſame diſtance from the load-water line T V that the lines which repreſent them in the plane of the projection are from it. In order to form theſe upon the horizontal plane,

1ſt, Take half the thickneſs of the poſt from the plane of the projection, and lay it off on the horizontal plane from A to E, and through the point

point E draw the line E *s* parallel to A B, five or fix feet long; lay off the fame diftance from B to F, and thro' the point F draw a line F R parallel to A B, five or fix feet long.

2d. From the points where the water lines interfect the ftern poft upon the plane of elevation, let fall perpendiculars. In like manner, let fall perpendiculars from the points where the water lines interfect the ftem.

3d. Take upon the water lines, in the plane of the projection, the feveral diftances intercepted betwixt the middle line and the curve of the midfhip frame, and lay them off from the line A B in the horizontal plane, upon the perpendicular that reprefents the midfhip frame. Take alfo from the plane of projection the feveral diftances intercepted betwixt the middle line and the curvings of the other frames, and lay them off in the horizontal plane from the line A B, upon the perpendiculars correfponding to their refpective frames, both in the fore body and after body, and curves paffing through all thefe points will give the true form of all the water lines; they end forward at the points where the perpendiculars interfect the line F R. The water lines abaft which end upon the poft in the plane of elevation, will end where the perpendiculars interfect the line E *s* upon the horizontal plane. But the 3d and 4th water lines cannot end upon the poft, by reafon of the fafhion pieces; and in order to find the points where thefe fhall end, we muft proceed in the following manner.

To find the point where the load-water line ends, let fall a perpendicular from the point *k*, where it interfects the fafhion piece on the plane of elevation, to N. Take from the plane of the projection upon the line that reprefents the load-water line, the diftance betwixt the fafhion piece and the mid-line; lay this off upon the horizontal plane from the line A B to the point N, which will end the load-water line upon the horizontal plane, from whence it may be drawn to *g*; fo *g* N will be the flat of the Tuck; and to find the point *g*, draw a line parallel to *k* N thro' the point where the line T V cuts the rabbit of the poft, which will give the point *g*. We may, after the fame manner, find the ends of the other water lines that do not go to the ftern poft for a fquare tuck.

To form the Ribbands upon the Horizontal Plane.

We obferved before, that the ribbands where thin planks nailed to all the frames from the poft to the ftem; and that when they are carried round, fo as to make fair curves, the form of all the filling timbers may be by them determined. Thefe filling timbers are to be placed betwixt the frames, which were methodically laid down in the draught. We ſhall here further obſerve, that theſe ribbands will round two ways, one in a vertical, and one in an horizontal ſenſe, occaſioned by the nature of the form of the ſhip's body; for they will, in carrying them about, naturally fly higher abaft and before than they are in midſhips, which gives them a vertical curve, and the narrowing of the ſhip's breadth from the midſhips both ways, gives them the horizontal curve; thence they will be repreſented by different lines on all the planes.

They are repreſented upon the plane of the projection by ſtreight lines, all but the breadth ribband, which is uſually repreſented by a curve; but upon the plane of elevation, and that of the horizon, they will be repreſented by curves. The reaſon of theſe different appearances ariſes from the different ſituations in which they are ſuppoſed to be viewed, as was obſerved in reſpect of the water lines.

Now, in order to comprehend the relation betwixt theſe horizontal curves, and the lines that repreſent them upon the plane of the projection, it will be ſufficient to remark, that theſe horizontal curves reſult from the different lengths of the perpendiculars that are ſuppoſed to be drawn in the plane of the projection, from the points where the lines that repreſent the ribbands interſect the frames, to the middle line. Hence, if the lengths of theſe perpendiculars are transferred to the lines correſponding to each frame in the horizontal plane, we ſhall have the points thro' which the curve that forms the ribband muſt paſs.

But if theſe ribbands are to be repreſented upon a plane placed in an oblique poſition to the horizon, that is to ſay, a plane that has the ſame inclination to another plane erected perpendicularly upon the middle line of the keel, that the line that repreſents that ribband, has to the middle line in the plane of the projection; in that caſe, they will have a quite different form from what they have upon the plane of the horizon.

Now, to conceive the relation betwixt theſe and the lines that repreſent them upon the plane of the projection, it will be ſufficient to remark, that if the ſeveral diſtances taken upon each diagonal intercepted betwixt the middle line and the points where theſe diagonals interſect the curves of the timbers in the plane of the projection; I ſay, if theſe be transferred to the lines that repreſent thoſe timbers, we ſhall have the points thro' which the curves that form the ribbands muſt paſs.

Again, if theſe ribbands are to be repreſented upon the plane of elevation, they will have a different form from any of the former; to find which, we need only take the perpendicular diſtances from the points where the diagonals interſect the curves of the timbers in the plane

of

of the projection to the line that reprefents the upper fide of the keel, and transfer them to the plane of elevation, fetting them up from the upper fide of the keel upon the line correfponding to the timber, from which they were taken upon the plane of the projection. This will give us the points thro' which their curves muft pafs.

Having thus given a general defcription of thefe curves, we fhall now proceed to defcribe them upon the different planes.

To defcribe the Floor Ribband upon the Plane of Elevation.

1ft. Take the perpendicular diftance betwixt the point *a*, where the diagonal interfects frame 9, and the lower water line in the plane of the projection.

2d. Set up this diftance from the point S, where the lower water line interfects frame 9 in the plane of elevation, and we fhall have a point G, thro' which the curve muft pafs.

Now, it is plain, that we may, by repeating the fame operations, have a point in each frame, thro' which the curve of the ribband muft pafs upon the plane of elevation. After the fame manner are all the other ribbands formed.

To defcribe the Ribbands upon the Horizontal Plane.

The breadth ribband is formed by transferring the lengths of all the perpendicuars that are fuppofed to be drawn from the points where the curve that reprefents this ribband interfects the timbers, to the middle line in the plane of the projection: This curve, in the plane of the projection, is drawn from the breadth in midfhips to the extremity of the wing tranfom.

1ft. Lay off the length of the wing tranfom upon the perpendicular N L.

2d. Take the length of the perpendicular drawn, from the point where the curve that reprefents the breadth interfects frame 9, to the mid-line in the plane of the projection; lay off this from the line A B upon the perpendicular reprefenting frame 9 in the horizontal plane, to the point S, which will be one of the points thro' which the curve of the ribband muft pafs. We may proceed in the fame manner to find points upon all the perpendiculars, both afore and abaft, fo fhall the curve L, S, Q, 1, be the form of the breadth ribband. But to compleat this ribband, the round aft of the wing tranfom muft be fet off.

To

To form the Oblique or Cant Ribbands.

We obſerved before, that theſe ribbands could not be formed either upon the horizontal plane or that of elevation, upon which account they were ſeldom drawn, becauſe each muſt be drawn upon a ſeparate plane. However, thoſe who incline to draw them may uſe the following method:

Let it then be required to form the firſt ribband repreſented in the plane of the projection, by the diagonal H G.

1ſt. Produce line H G to the point *p* in the middle line upon the plane of the projection.

2d. Take the height of the point *p* above the line that repreſents the upper ſide of the keel in midſhips, in the plane of the projection; ſet up this from the ſame line in the plane of elevation, on a perpendicular, upon the poſt, from which point let fall a perpendicular to the point F in the line C D, and produce all the perpendiculars that repreſent the frames to the line C D; ſo F Q will be the axis of the ribband from the poſt to the midſhips.

3d. Take upon the plane of the projection, in the line H *p*, the diſtance *p* G, which ſet off upon the perpendicular from the point F to *f*.

4th. Take the diſtance on the diagonal from the point *p* in the middle line to its interſection with the frame 9. Set off this from the line C D upon the perpendicular correſponding to frame 9; this will give us a point thro' which the curve muſt paſs. Do the ſame for all the other frames to the midſhip.

In like manner the curve for the fore part of the ribband is formed from the interſections of the diagonal 4, 5, with the curves of the frames in the plane of the projection; but it is evident, this is a different plane from that of the line H *p*; therefore we muſt have a different axis for the curve of the fore part of the ribband. In order to which, take from the plane of the projection the diagonal 4, 5; ſet off this from the point O to Z, and draw the line Z X parallel to C D. We muſt likewiſe take the height of the point 4 in the plane of the projection, and ſet it up on the ſtem; from which point letting fall a perpendicular to the line Z X, we ſhall limit the fore end of the ribband. The points thro' which the curve muſt paſs will be found the ſame manner as thoſe for the after-body.

The builders make uſe of the cant ribbands to find the bevellings of the timbers; for we muſt repreſent each frame as one intire piece of circular timber, and being all faſtened to the keel they form the ſide of the ſhip. They are ſquare upon the upper ſide of the keel; but becauſe both

both the outside and inside of the ship's sides, length-ways, form curves, it is plain, that the sections of any of the frames, the midship only excepted, will produce a surface in the form of a lozenge or rhombus; the angles which are formed by these sections are what are called the bevellings of the timbers.

The ship-wrights take these angles mechanically by an instrument called a bevel; thus they draw, upon the plane of the ribband, a line parallel to that which represents the frame, and distant from it the whole breadth of the timber; and applying the stock of the bevel to the line that represents the frame, and the tongue to the ribband, they have the quantity of the angle which forms the bevelling of the timer at that place.

It is plain the angle *b*, *a*, *c*, which points to the midship frame, will be obtuse, whereas the angle *b*, *a*, *d*, which points to the post, will be acute.

Now, as every timber has two planes, that which points to the midships will have what they call a standing bevelling, and that which points either to the post or stem will be under bevelling.

We shall shew in another place how the modern builders, by putting the frames in an oblique position to the keel afore and abaft, lessen the bevellings.

CHAP. VI.

Another Method of laying down the Horizontal Plane, and the Plane of Projection.

THOSE who are well versed in the art of drawing have taken a method quite different from any of those we have described, which shall be the subject of this chapter.

After forming the plane of elevation, and drawing all the perpendiculars for the frames, as before, the following method must be observed:

I.

To lay down the Breadth Ribband on the Horizontal Plane.

The extremities of it on the stem and post, and the point thro' which it is to pass on the midship frame are found as directed in the preceeding chapter. It remains now to find the points in the balance frames, thro' which it is to pass.

To find the point in the fore balance frame take $\frac{181}{200}$ parts of half the main

main breadth, which set off on the line that represents that frame in the horizontal plane from K to L.

To find the point in the balance frame abaft, take $\frac{234}{200}$ parts of the half of the main breadth from M to N. It will be necessary to have another point in the fore body, thro' which the curve must pass; for which purpose use the following method:

Divide the space contained betwixt the line that represents the balance frame afore and the rabbit of the stem, into two equal parts, and draw the line *o p*, on which set off the 160th part of the main breadth, which will give the point *p*, thro' which the curve is to pass. It must be observed, that the proportions for finding these points may be varied according to the form we propose to give to the ribband. After the points H, N, Q, L, *p*, *s* are thus set off, we may describe the curve either by moulds or penning battens.

II.

To lay down the Floor Ribband on the Horizontal Plane.

1st. The height of this ribband must be determined both upon the post and stem, from which points letting fall perpendiculars, we shall have the extremities of it on the horizontal plane, observing to allow for the rabbit.

2d. Take half the length of the midship floor timber, and set off on the line that represents the midship frame on the horizontal plane from *a* to *s*, which will be the point thro' which the curve must pass.

3d. Take $\frac{143}{200}$ of the line *a s*, the breadth at the midship frame, and set it off on the balance timber afore, from K to T, and set off $\frac{149}{200}$ of the same line, upon the balance timber abaft to V, and draw the curve thro' the points G, V, S, T, R.

III.

To lay down the after Balance Timber upon the Plane of Projection.

1st. Produce the line which represents it on the horizontal plane to the sheer rail, on the plane of elevation, and take the distance upon this line betwixt the upper side of the keel, and the lower edge of the second wale, which here represents the breadth ribband; set up this from A to C on the plane of the projection, from which point draw the line C D, perpendicular to the middle line. (*Plate* II. *Fig.* 1, 2, 3.)

2d. Take the line M N in the horizontal plane, and set off from D to E, which will give one point, through which the curve of the timber must pass.

3d. Take

3d, Take the height of the floor ribband, in the plane of elevation, and ſet it up on the plane of the projection to G; from the point H, at the end of the floor timber, draw the line H G, which will repreſent the floor ribband on the plane of the projection. (*Plate* II. *Fig.* 1. 2. 3.)

4th, Take the diſtance M V, in the horizontal plane, with a pair of compaſſes, and move the compaſſes with one foot, in the middle line, and the other in a line perpendicular to it, till it interſect the diagonal in the point L, thro' which the curve of the frame muſt paſs. To thoſe who are acquainted with drawing, the three points E, L, F, will be ſufficient to form the timber; they who incline to have another point may divide the line A C into two equal parts by a perpendicular M K, drawn to the middle line, from which ſetting off $\frac{138}{200}$ of the line M K, we ſhall have another point thro' which the curve muſt paſs.

IV.

To lay down the ninth Frame abaft on the Plane of the Projection.

Take the height of the breadth ribband at this frame, in the plane of elevation, and ſet it up on the plane of the projection from F to O, and draw the line O P perpendicular to the middle line. (*Plate* II. *Fig.* 1. 2. 3.)

2d, Take the diſtance X S in the horizontal plane, and ſet off from O to P, which will be the point thro' which the curve muſt paſs.

3d, Take the diſtance X Z in the horizontal plane, which ſet off from the middle line, to interſect the diagonal that repreſents the floor ribband, in the plane of projection in Q, obſerving to keep the compaſſes as before directed.

4th, Divide the line K O in two equal parts, and draw the line R S perpendicular to the middle line, ou which ſet off $\frac{154}{200}$ of the line P O, from R to S, and draw the curve thro' the points P, S, Q, F, which will be the form of the ninth frame.

V.

To lay down the intermediate Ribbands abaft on the Plane of the Projection.

1ſt, Take the diſtance betwixt the upper ſide of the keel and the breadth, upon the line that repreſents the midſhip frame, in the plane of elevation, and ſet it up from A to T, and from B to T, in the plane of the projection, ſo ſhall the line T T give the height of the breadth ribband in midſhips.

2d, Divide the curve H M T into as many equal parts as there are to be intermediate Ribbands; divide alſo the curve of the ninth frame Q S P into the ſame number, and, thro' theſe diviſions, draw the diagonals which will repreſent the ribbands as in the plate.

VI.

To lay down the first intermediate Ribband upon the Horizontal Plane.

1st, Take the nearest distance of the point V (which is the extremity of the diagonal in the plane of the projection) to the middle line O F, set off this on the line which represents the midship frame in the horizontal plane, which will give the point thro' which the curve must pass at that place. After the same manner we may find the points in the lines that represent the balance and ninth frames in the horizontal plane.

2d, Take F Z, the height of the ribband upon the rabbit of the post, in the plane of the projection, and set it up on a perpendicular, to the point *k*, on the line that represents the rabbit of the post in the plane of elevation; take the nearest distance of the point *k* to the perpendicular of the post, which set off from F to *e*, and this will be the end of the ribband: So a curve passing thro' the points *e*, *d*, *c*, *b*, will be the form of the ribband.

VII.

To lay down the Wing Transom upon the Plane of the Projection, and on the Horizontal Plane.

1st, Take the height of the upper side of the wing transom (including the round up) in the plane of elevation, and set it up in the plane of the projection to the point *e*.

2d, Take the height in the plane of elevation, without regarding the round up, and set off from F to *f*, and draw the line *f g* perpendicular to the middle line, on which set off the length of the transom from *f* to *g*, this is equal to the line G H in the horizontal plane. The curve *g e* represents the upper side of the wing transom.

The round aft of the transom is represented upon the horizontal plane by the curve L *k e*; H L is the square end of it.

VIII.

To lay down all the Frames in the after Body.

All these are laid down in the same manner as the ninth and balance frames before described, that is, by taking the half breadth of the ribbands at each frame in the horizontal plane, and setting them off from the middle line in the plane of the projection to intersect the diagonal corresponding to the ribband, as directed in forming the balance frame, by this means we shall divide each into as many points as there are frames: The curves drawn thro' these points will give the form of all the frames in the after body.

IX. *To*

IX.

To lay down the Position of the Fashion Piece on the Horizontal Plane.

Let fall the perpendicular G H, from the end of the wing transom, and draw the line H *l*, which will represent the plane of the fashion piece upon the horizontal plane, observing to make the angle G H *l*, about 25 degrees.

X.

To form the Fashion Piece in the same manner it is to be, when put into its proper place in the Ship.

The fashion piece laid down in the plane of the projection, regards that frame as it would appear when viewed from abaft; but as the fashion pieces on each side are not in one plane, as all the rest of the frames are, we shall be much deceived, if we imagine that the fashion piece laid down in the plain of projection, will give the true form of that which is to be put in the ship. We must therefore lay it down upon another plane, and, to avoid confusion, we shall separate it from the plane of projection.

Note, The fashion peice, mention'd by our author, described in the plane of the projection, is that betwixt the ninth frame, and the curve f q o G, *which represents the fashion piece of a square tuck; it is formed in the same manner as the rest of the frames, by tranferring the lines* n m, p o, *&c. in the horizontal plane, to the plane of projection, to interfect the diagonals corresponding to these ribbands in the points* i, l, *&c*:

1st, Draw the line *f* G, to represent the middle line of the plane of projection. (*Fig.* 4.)

2d, Draw the line *f g* perpendicular to G *f*, to represent the wing transom.

3d, From *i*, the point where the fashion piece intersects the floor ribband in the plane of the projection, take the nearest distance to the line *f g*, which represents the wing transom, and set off this distance in *Fig.* 4. from *f* to *h*, and draw the line *h l* parallel to *f g*.

4th, From the point *l*, where the fashion piece intersects the first intermediate diagonal, in the plane of projection, take the nearest distance to the line *f g*, set it off from *f* to *k*, in *Fig.* 4, and draw the line *k m*, parallel to *f g*.

5th, In like manner, the points where the fashion piece intersects the second and third diagonals in the plane of projection, are to be transferr'd to the points *q* and *n*, *Fig.* 4, and the lines *p q*, *n o*, drawn parallel to *f g*.

 6th,

6th, To find the points through which the curve muſt paſs: Take the line *l* H, which repreſents the poſition of the faſhion piece upon the horizontal plane; lay this off from *f* to *g*: Again, take the diſtance *l y* in the horizontal plane; which lay off from *q* to *p*, in like manner ſet off the diſtance *l z*, from *n* to *o*; and the diſtance *l p* from *k* to *m*, and laſtly, the diſtance *l n*, from *h* to *l*; ſo a curve drawn through the points *g*, *p*, *o*, *m*, *l*, will give the true form of the faſhion piece.

XI.

To lay down the Faſhion Piece upon the Plane of Elevation.

1ſt, Take the ſeveral heights above the keel, of the points where the faſhion piece interſects the diagonals in the plane of projection, and transfer them to the lines *o*, *p*, *q*, *z*, *y*, in the plane of elevation, drawn parallel to the keel, and the ſame height above it, that their correſponding points are in the plane of projection.

2d, Take the neareſt diſtance of the point *n*, in the horizontal plane, to the line C F, the perpendicular from the head of the poſt, ſet off this from the ſame line in the plane of elevation upon the line *p*; which will be the point through which the curve muſt paſs.

3d, In like manner the points *z*, *y*, muſt be transferr'd from the horizontal plane, to the plane of elevation in the points *z*, *y*, a curve paſſing through theſe points will be the projection of the faſhion piece on the plane of elevation.

We ſhall hear remark, that ſome builders to avoid giving a great bevelling to the timbers, and likewiſe that they may not require ſuch compaſs timber, do change the direction of all the frames in the fore-body before that of the loof; that is, the lines that repreſent them in the horizontal plane make an acute angle with the line that repreſents the keel; theſe are called cant timbers, and may be formed in the ſame manner as the faſhion piece, which we have now deſcribed. Tho' ſeveral builders form all the frames perpendicular to the keel, to have the floor timbers in one piece, which will be much ſtronger that when in two pieces, and this will inevitably be the caſe when the timbers are canted.

We might here ſhew how to lay down the top timbers, but as that part under water is the moſt material, we ſhall proceed to form the timbers afore.

XII.

To lay down the Frames for the Fore-body.

The balance and the eighth frame muſt firſt be formed in the ſame manner as the balance and ninth frame abaft: In order to which the curve

that

that represents the breadth ribband must be laid down in the plane of the projection afore. The diagonal, which represents the floor ribband, must likewise be laid down in the plane of the projection, for which purpose we must take the height of the ribband above the keel, upon the rabbit of the stem, and set it upon the line that represents the rabbit of the post in the plane of the projection, to the point 4; from which draw a line to the floor head, so 4 5 will represent the floor ribband.

XIII.

To space the Diagonals that represent the Ribbands afore, in the Plane of the Projection.

1st. As the points of their intersection at the midship frame are the same afore that they are abaft, we need only transfer them from abaft to the fore body.

2d. Take the height of the breadth ribband upon the stem, in the plane of elevation, and set it up from F to 17 in the plane of projection.

3d. Divide the distance betwixt 4 and 17 into four equal parts, which will give the points in the plane of projection, where the immediate diagonals end on the stem.

After the diagonals are drawn in the plane of the projection, the ribbands may be laid down in the horizontal plane, and from thence all the other frames may be laid down in the plane of projection, in the very same manner that the horizontal ribbands and the frames for the afterbody were laid down.

CHAP. VII.

General Remarks on Ship Building.

ALL the rules we have hitherto laid down, collected from the principal dimensions of ships built by the most eminent masters, should only be so far regarded as they may assist the artist in forming the body in such a manner as to produce effects answerable to the service for which the vessel is designed.

In order to qualify a builder for such an undertaking, it is necessary he should understand the nature of fluids, and of such bodies as will float in the water; when he has made himself acquainted with these, I would recommend him to M. *Bouguer*'s treatise on ship-building.

The principal Qualities belonging to Ships.

1st. To be able to carry a good sail, not only because, in forming the body, the water lines are all supposed to be described when a ship is upright in the water, but likewise for doubling a cape, or getting off a lee shore, which will be impossible to be done when a ship lies over in the water, this will likewise render her lower tier, if not all her guns, useless.

2d. A ship should steer well, and feel the least motion of the helm.

3d. A ship should carry her lower tier of guns four feet and a half, or five feet out of the water, otherwise a great ship, that cannot open her ports upon a wind, but in smooth water, may be taken by a small one, that can make use of her guns, or she must bare away before the wind, to have the use of her guns; on which account it will be proper to raise the ports higher before than in midships, because the fore part of the ship is often pressed into the water by carrying sail.

4th. A ship should be duly poised, so as not to dive or pitch hard, but go smooth and easy through the water, rising to the sea when it runs high, and the ship under her courses, or lying to under a mainsail, otherwise she will be in danger of carrying away her masts.

5th. A ship should sail well before the wind, large, but chiefly close hawled, keep a good wind, not fall off to the leeward.

Now the great difficulty consists in uniting so many different qualities in one ship, which seems indeed to be impossible; the whole art therefore consists in forming the body in such a manner, that none of these qualities shall be entirely destroyed, and in giving the preference to that which is most required in the particular service for which the vessel is built; in order to which

which, it will be neceſſary to know, at leaſt nearly, what form will give a veſſel one of theſe qualities, conſidered abſtractly from the reſt.

To make a Ship carry a good Sail.

A flat floor timber, and ſomewhat long, or the lower futtock pretty round, a ſtreight upper futtock, the top timber to throw the breadth out aloft; at any rate to carry her main breadth as high as the lower deck: Now, if the rigging be well adapted to ſuch a body, and the upper works lightened as much as poſſible, ſo that they all concur to lower the center of gravity, there will be no room to doubt of her carrying a good ſail.

To make a Ship ſteer well, and quickly anſwer the Helm.

If the faſhion pieces be well formed, and the tuck carried pretty high; the midſhip frame carried pretty forward; a conſiderable difference of the draught of water abaft more than afore; a great rake forward, and none abaft; a ſnug quarter-deck and forecaſtle, all theſe will make a ſhip ſteer well; but to make her feel the leaſt motion of her helm, it will be neceſſary to regard her maſts. There is one thing not to be forgot, that a ſhip which goes well will certainly ſteer well.

To make a Ship carry her Guns well out of the Water.

It is plain, that a long floor timber, and not of a great riſing; a very full midſhip frame, and low tuck with light upper works, will make a ſhip carry her guns high.

To make a Ship go ſmoothly through the Water without pitching hard.

A long keel, a long floor, not to riſe too high afore and abaft, the area or ſpace contained in the fore body, duly proportioned to that of the after body, according to the reſpective weights they are to carry; all theſe are neceſſary to make a ſhip go ſmoothly through the water.

To make a Ship keep a good Wind.

A good length by the keel, not too broad, but pretty deep in the hold, which will occaſion her to have a ſhort floor timber, and great riſing.

As ſuch a ſhip will meet with great reſiſtance in the water, going over the broad-ſide, and little when going a-head, ſhe will not fall much to the leeward.

Now, ſome builders imagine that it is not poſſible to make a ſhip carry her guns well, carry a good ſail, and to be a prime ſailer, becauſe it would

would require a very full bottom to gain the firſt two qualities, whereas a ſharp ſhip will beſt anſwer for the latter; but when it is conſidered that a full ſhip will carry a great deal more ſail than a ſharp one, a good artiſt may ſo form the body as to have all theſe three good qualities, and likewiſe ſteer well, for which purpoſe I would recommend ſomewhat in length more than has been formerly practiſed.

After what has been ſaid upon this head, I believe it will nòt be thought impoſſible to unite all theſe different qualities in one ſhip, ſo that all of them may be diſcerned in ſome degree of eminence; but when it happens otherwiſe, the fault muſt be owing to the builder, who has not applied himſelf to ſtudy the fundamental rules and principles of his art.

Excepting ſome antient builders, who were happily born with a natural genius, and our moderns, who being inſtructed in the principles of the mathematics, have truly laboured very hard to make a progreſs in the art of ſhipbuilding, one may, without violating the truth, affirm that the greateſt part ſatisfy themſelves with copying ſuch ſhips as they eſteem good ſailers, and it is theſe ſervile mechanick methods, which, to the great reproach of the art, are but too common, that have produced all theſe pretended rules of proportion, all theſe methods of deſcribing the midſhip frame, and forming the reſt of the timbers, which every builder endeavours if poſſible to conceal, and keep wholly in his own family.

How low and mean is this? it is as if a great architect ſhould endeavour to conceal the proportions of the different orders of architecture; whereas they are publiſhed every where, and ſo well known that many can raiſe a very beautiful porch or triumphal arch; but tho' the methods of deſcribing the midſhip frame, and forming the reſt of the timbers, be known to moſt apprentices, yet we have but few good maſter builders: This requires more than thoſe mechanick rules; they ſhould at leaſt have ſuch a knowledge of the mathematicks, phyſicks, mechanicks, of the nature of ſolids and fluids, as to be able to diſcover what figure would procure ſome good quality, without hazarding or putting a bad one in its place.

Let us ſuppoſe one to have a collection of draughts of a vaſt number of ſhips, and whoſe good and bad qualities have been remarked with all poſſible exactneſs, ſuch a valuable treaſure would be of great ſervice to a perſon who could calculate preciſely by the draughts where the fault lay, and how it might be rectified. For inſtance, ſuppoſe a ſhip ſails well, but carries her guns too low, a builder who is not acquainted with theſe principles would raiſe her deck, in conſequence of which ſhe would not ſail well; whereas, one that could exactly calculate how much the reſiſtance of the fluid is diminiſhed upon the prow, would take great care to to add no more to any of the other parts than he could find by an exact calculation might be done without augmenting the resistance in the fluids.

M. *Bouguer* has published several useful problems for making these calculations, to which we refer the reader, and only explain what regards the height of the gun deck, and the resistance of the fluid, in one example of a 70 gun ship.

CHAP. VIII.

To know by the Draught how high a Ship will carry her Guns out of the Water.

THIS is only to know if, when a ship is loaded with all her ammunitions and provisions on board, and ready to sail, her seat in the water will then agree exactly with the load water line in the draught.

It may be demonstrated by several experiments, that any floating body of whatsoever figure will just sink so far in the water as to displace a bulk of water of equal weight with itself.

Hence it will be necessary, first to find a method of calculating the exact weight of a ship ready equipt for sea, and secondly, to know the exact weight of the water the ship displaces, when loaded to the water line in the draught.

In order to the first, the exact weight of all the timber, iron, lead, masts, sails, rigging, and in short of all the materials, men, provisions, and every thing else on board the ship must be known.

It must be confessed that this is a very laborious task, yet the zeal of our modern builders has surmounted all these difficulties, and got the exact weight of a ship of each class, with all its furniture, and six months provisions on board. It will be sufficient for our purpose to give the particulars, of the two following, one of 30 and another of 50 guns, both ready equipt for sea, with six months provisions on board.

An Estimate of the Weight of the RENOMEE *Frigate of Thirty Guns, with Six Months Provisions.*

WEIGHT of the HULL.

		Cubic feet	Under water Pounds	Above water Pounds.	Total Tons	Total Pounds
Oak timber	under w. at 72 *lb.* per f.	5640	406080		299	800
	above w. at 66 *lb.*	2920		192720		
Fir at 50 *lb.* per foot	under water	600	30000		29	000
	above water	560		28000		
Carved work				2200	1	200
Iron knees and standards			4200	7010	5	1210
Bolts, rudder irons, chain plates, nails			11650	6558	9	208
Lead for the hause holes & scuppers			250	430	0	680
Locks				170	0	170
Oakum			1200	1830	1	1030
Pitch and Tar				650	0	650
Paint				440	0	440
In the Cook room				8000	4	000
	Total		453380	248008	350	1388

WEIGHT of the FURNITURE.

	Under W. Pounds.	Abov W Pounds.	Total. Tons	Total. Pds
Masts compleat set and spare	3000	37000	20	00
Blocks	1000	5444	2	444
Pumps	1734	670	1	404
Cables and Hawsers	24444		12	444
Sails and their Cases	4222	3778	4	000
Anchors and their Stocks	[illegible]	6944	4	1555
Cordage for the rigging		17282	8	1282
The master's Stores	3333		1	1333
Boats		6666	3	666
Total	40344	75784	58	128

WEIGHT of the PROVISIONS, &c.

	Under water. Pounds.	Above water Pounds.	Total Tons	Total Pounds
Provisions for 6 months for 200 men with all their equipage	245420		122	1420
Water for two months and a half	100000		50	000
Casks	32800		16	800
The Captain's table	15000	5000	10	000
Total	393220	5000	199	220

WEIGHT of the OFFICERS STORES.

	Under water Pounds.	Above water Pounds.	Total Tons	Total Pds
The Carpenter's Stores	3000	1000	2	00
The Caulker's Stores	1000		0	1000
The Surgeon's Effects	2400		1	400
The Pilot's Effects	740	360	0	1100
The Chaplain's Effects		100	0	100
	7140	1460	4	600

WEIGHT of the GUNS and AMMUNITION.

	Under water Pounds.	Above water Pounds.	Total Tons	Total Pds
Iron Guns		60300	30	300
Carriages fitted		14000	7	00
Balls round and cross bar	11570	2430	7	00
Balls of one pound	600		0	600
Powder and Powder Barrels	7108	112	3	1220
Implements for the powder	1368	132	0	1500
Crows, Handspikes, Gunners Utensils, and Stores	3200	1500	2	700
Musquets, Cutlasses, and Pole Axes		900	0	900
	23846	79374	51	1220

WEIGHT of the MEN and their EQUIPAGE.

	Under water Pounds.	Above water Pounds.	Total Tons	Total Pounds
8 principal Officers and their Effects		4000	2	00
200 Men and their Effects		40000	20	00
Total		44000	22	00
BALLAST	200000		100	00

RECAPITULATION.

	Under water Pounds.	Above water Pounds.	Total Tons	Pounds
The Hull	453380	248008	350	1388
The Furniture	40344	75784	58	128
The Provisions	393220	5000	199	220
Officers Stores	7140	1460	4	600
Guns and Ammunition	23846	79374	51	1220
Weight of the Men		44000	22	00
Ballast	200000		100	00
Total	1117930	453626	785	1556

An Estimate of the Weight of a Frigate of Fifty Guns, with Six Months Provisions.

	Under water Pounds.	Above water Pounds.	Total Tons	Pounds
The Hull	774270	769134	771	1404
The Furniture	98237	163184	130	1421
Ballast	300000		150	000
Guns and Ammunition	679400	199320	133	1280
Provisions	659400	8060	333	1400
Stores	9800	2800	6	600
Men and their Equipage		77000	38	1000
Total	1909667	1219438	1564	1105

But as all ships of the same class are pretty near the same dimensions, and have the same number of guns, &c. we may have the exact weight of each only by examining the draught of water, and computing the weight of that column of water which is displaced by the ship.

Now if the *Intrepide* weighs 2718 tuns, she must sink so far into the water till she has displaced a column of water containing 73459 $\frac{17}{37}$ cubick feet, for a cubick foot of salt water being supposed to weigh 74 lb. the 73459 $\frac{17}{37}$ will weigh 5436000 lb. or 2718 tuns, or if she displaces 73459 $\frac{17}{37}$ cubick feet of salt water, we may thence conclude that she weighs 2718 tuns.

In like manner, if the weight of the ship which is to be laid down in the

the draught be known; as, for instance, that if a ship of 78 guns, is 2350 tons, we may with certainty know if the water line in the draught be properly placed, only by reducing the bottom into cubick feet.

The antient builders were unacquainted with the manner of performing this, but our moderns make an exact calculation of the contents of the bottom before they begin to build, whereby they will be sure to keep the lower tier of guns well out of the water.

If a ship's body were any regular figure, the solid contents of it could easily be found geometrically, but as the case is quite otherwise, we must be satisfied with dividing it into several parts, of which we may have a great number, and they will thereby become so small, that they may, without any sensible error, be esteemed as regular figures, limited by streight lines, tho' some of them are actually curves.

In the draught of the 70 gun ship which we have laid down, the bottom is divided on the plain of elevation into several parts, in a vertical way, by the lines that represent the frames; and in an horizontal way by the water lines; so that the whole may be said to be divided into so many parallelopipedons, A, B, C, D, or *a*, *b*, *c*, *d*, contained betwixt the two frames 6 and 7, and limited on the side A B by a plain supposed to be erected vertically upon the keel, and on the other side by the round of the outside of the ship, at the height of the breadth water line, or *a c*. Now it is very plain that the area of the surface, which limits the lower part of this solid, is less than the area of the surface, which limits the upper part: But if we increase the water lines and frames, we may find the solid contents to a sufficient exactness for our purpose.

Now, in order to find the area of the upper surface A B C D, let A C be 16 feet 11 inches, and BD 13 feet 6 inches; add these two, the sum is 30 feet 5 inches, the half of which is 15 feet 2 inches and a half, and this sum multiplied by A B, which suppose 8 feet, the distance betwixt the frames, the product is 121 feet 8 inches, the area of the upper surface of the parallelopipedon.

The area of the lower surface of the parallelopipedon may be found after the same manner, which suppose 97 feet 4 inches. Now, if these two areas be added together, their sum will be 219 feet, the half of which is 109 feet 6 inches for the mean area, and this multiplied by *a b*, the distance betwixt the water lines, which suppose 4 feet 4 inches, produces 474 feet 6 inches cubick.

By the same process we may find the solid contents of the other parallopipeds, and adding them together, and doubling that sum, we shall have the

the solid content of the whole bottom of the ship in cubick feet to a sufficient degree of exactness.

I made use of this method before M. *Bouguer*'s treatise was published, where there is one which is more convenient and expeditious, for, instead of finding the area of every single surface contained betwixt the frames upon the section of a water line, he finds by one operation the area of the whole surface formed by the horizontal section or water line, except that part intercepted betwixt the aftermost frame and the post, and the part contained betwixt the foremost frame and the stem, which, upon account of the rake must be measured seperately, as also all that lies betwixt the upperside of the keel and the first water line. His method is as follows:

Take the lengths of all the lines that represent the frames on the horizontal plane, add all these together, excepting the foremost and aftermost, of which take only one half of each, so if it were required to find the area of the surface formed by a horizontal section in the plane of the load water line, it will be $\frac{1}{2}$ ZZ+BD+AC+IH+LK, &c. +KS×AB, supposing AB to be the distance betwixt the frames equally spaced betwixt ZZ and NO,

To demonstrate this, let it be considered by what operation the two trapezia ABDC and HIAC are measured. We observe in the proceeding article that this was performed by adding the length of the lines BD and AC together, and then taking half that sum; the length of the lines AC and HI, must likewise be added together, and the half of that sum taken; now it is evident that it will be the same thing to take half the line BD, and half the line HI, and the whole line AC, and add all these three together, because the line AC, is common to both the trapezia.

After the areas of all the water lines are thus found, the solid content of the space contained betwixt the water lines may be had by multiplying the area by the distance between the water lines: But, because the areas of the two surfaces which limits this part are unequal, a mean area must be found; this is half the sum of the two areas, so that all that is now to be done, is to add the areas of the water lines into one sum, excepting that of the upermost and lowermost, of which only one half of each must be taken, and if this sum is multiplied by the distance betwixt the water lines, the product will give half the solid content of the bottom, observing that the water lines in the plain of elevation be equally distant from one another.

The application of this method in finding the cubick feet contained in a 70 gun ship laid down in the draught.

The

The forepart is divided into eight, and the after into nine equal parts, besides that betwixt the aftermost timber and the post, and that betwixt the foremost timber and the stem.

The bottom is likewise divided into four equal parts by water lines drawn parallel to the load water line, all which are formed upon the horizontal plane; for it will be very useful to know the solid content of each particular part contained betwixt the water lines, also to distinguish that of the fore body from the after body, whereby we may be enabled to know if the weight be duly poised. We shall consider all this in the following calculation.

Note, there must be four inches added to each line that represents the frames in the horizontal plane for the thickness of the plank, that being nearly a mean betwixt the thickness of the plank next the wale, and that next the keel.

The Area of the Upper Water Line abaft.

The breadth of the surface at the load water line, upon the midship frame *a* Q is 21 feet 2 inches,

		feet.	inch.
	one half is	10	7
Breadth at	1st Frame	21	2
	2d Frame	20	11
	3d Frame	20	9
	4th Frame	20	5
	5th Frame	19	11
	6th Frame	18	11
	7th Frame	17	4
	8th Frame	15	7
The 9th Frame XS is 12 feet 9 inches, one half of which is		6	$4\frac{1}{2}$
	Total	171	$11\frac{1}{2}$
which total doubled is 343 feet 11 inches, and multiplied by 8, the distance betwixt the frames, is the whole area of the water line, from the midship to the after frame, in cubick feet		2751	4

To this must be added the area of the trapezium XSL*e*

Now half of the lines XS and L*e* is 10 feet 0 inches

Distance betwixt them is 9 9

Product is 97 6

	feet	inch
which being doubled is	195	0
The whole area in cubick feet	2946	4

By using the same process, we may find the areas of all the other water lines; and adding all these areas together, excepting that of the first and fifth, of which taking only one half, multiply this sum by 4 feet 5 inches, which

which is the distance betwixt them, we shall have the area in cubick feet of that part of the ship abaft the midship frame, contained betwixt the lower water line, and load water line.

	feet	inch.	l.	p.	
Half of the area of the load water line ——	1473	2	0	0	
Whole area of the 4th water line ——	2516	1	4	0	
Whole area of the 3d water line —— ——	2052	0	4	0	
Whole area of the 2d water line —— ——	1452	10	7	6	
Half the area of the 1st water line ——	144	3	2	0	
Total	7638	5	5	6	
Multiplied by the distance betwixt the water lines ——	4	5	0	0	
Product in cubick feet betwixt the lower and load water line	33736	6	1	3	6
Betwixt the lower water line and keel ——	333	6	3	0	0
Keel and post —— —— ——	101	8	0	0	0
Cubick ft. abaft the midship frame under water, when loaded	34171	8	4	3	6
Cubick ft. before the midship frame under water, when load.	28928	6	1	0	0
Total cubick feet under water ——	63100	2	5	3	6
Multiply by the weight of a cubick foot of salt water ——		pounds 74			
	pounds.	tons.	lb.		
Weight of the whole ship, with all her furniture, provisions, *&c.*	4661498	2334	1498		

We have omitted the operation for the fore part, because it is performed exactly by the same method with the after part.

It must be observed, that in finding the cubick feet of that part contained betwixt the lower water line and upper side of the keel, we must take the heights of all the frames intercepted betwixt these two lines, and divide their sum by the number of frames abaft the midship, the quotient will be 1 foot 9 inches 9 lines.

	Feet	In.	Lines
The area of the lower water line is ——	288	6	4
The area of the upper side of the keel — —	79	6	0
Total	368	0	4
One half is	184	0	2
Area of that part contained betwixt the lower warer line and keel	333	6	3

The use of the preceding calculation is to know if the load water line upon the draught be properly placed.

It has been found that a ship of 70 guns, with every thing on board, should weigh nearly 2350 tons, which is only 15 tons 1297 pound more than what is found by calculating from the load water line in the draught, this difference would occasion the ship not to draw above one inch more

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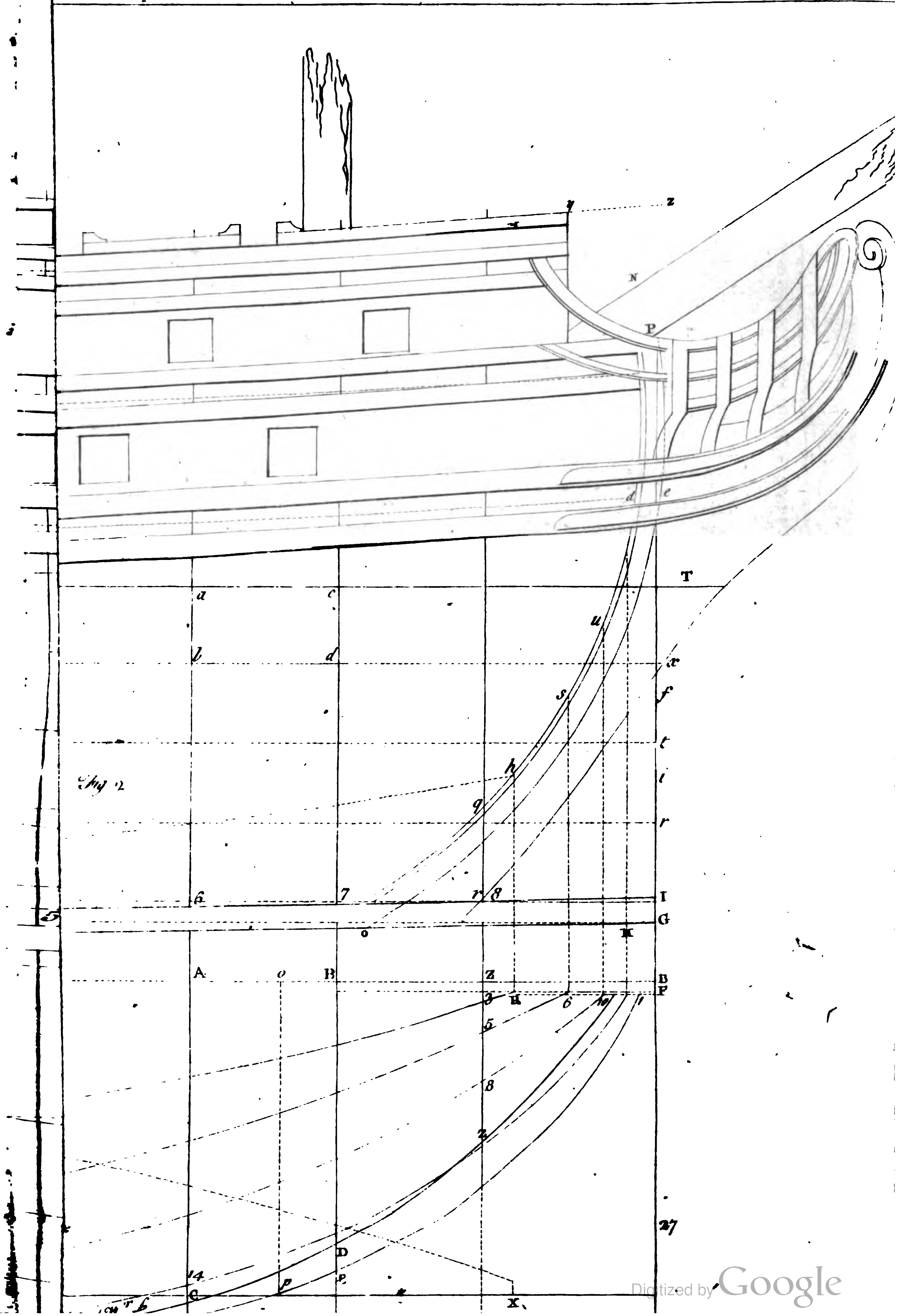


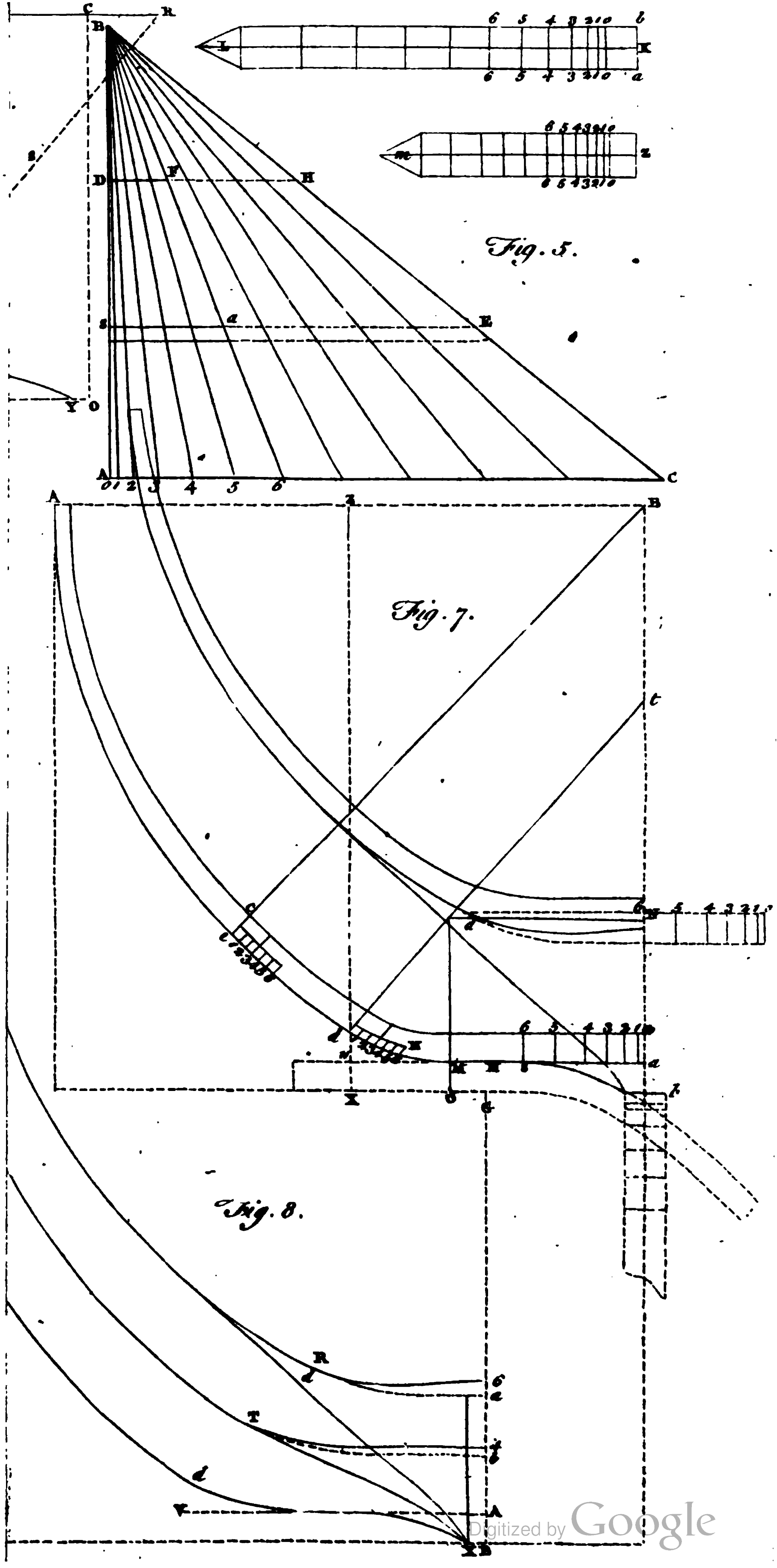


Fig. 5.
Fig. 7.
Fig. 8.

water it is not worth the regarding. But then by this calculation we discover that the ship is too lean before; for whereas the fore part should exceed the after part by 30 tuns, we find, by this calculation, that the after part exceeds the fore part by 193 tuns 1995 pounds.

Upon this account we must consider carefully if the midship frame is properly placed; it is here 5 feet before the middle. If the midship frame was exactly in the middle it would augment the weight of the fore part 102 tuns 307 pounds, and diminish that of the after part exactly the same quantity, by which means the fore part would be 1172 tuns 1014 pounds, and the after part 1162 tuns. Now we may fill out the fore part, so as to gain 15 tuns 636 pounds, which was deficient, to make the calculation taken from the draught agree with the real weight proposed for a ship of 70 guns fitted out for sea, with six months provision on board; and the fore-body will weigh 25 tuns 1255 pounds more than the after part, which may be judged sufficient.

CHAP. IX.

A Method to calculate the Resistance of the Water upon the fore Part of the Ship.

DAILY Experience sufficiently proves that the fluids, by their motion, attack the solids that oppose them, as bridges, mills, *&c.* with such violence as to carry all before them; and this is agreeable to the very nature of fluids.

For all fluids are an assemblage of a prodigious number of small solid bodies of a globular form, each of which being easily put in motion will act upon any surface with the same force that any other solid body of the like mass would do. But as these particles have but a very small cohesion with each other, fluids cannot act with the same force as solids which have their parts united.

A mass of water of 20 cubical feet will not act with the same force upon the pier of a bridge which opposes it, as a mass of ice of the same dimensions; because the whole mass of ice having its parts so united together, that one cannot advance without the other, it gives the blow with the united force of all the parts at once, whereas the parts that compose the mass of water, being but slightly united, they cannot act jointly or in concert, and they exert their force one after another; they indeed succeed one another immediately, and are a little united by their reciprocal pressure; but as every part has its own peculiar velocity, so it makes its effort singly by itself, and, being easily put in motion, it will be as easily turned out of its direction, the parts being only retained together by the weight of those that come next them.

Fluids have a continual effort, because when a certain number have produced their effect they are succeeded by others as long as the current lasts.

Hence it will follow, that when a vessel is left to a current of the river, it can receive no more velocity than the current has, and its velocity will be accelerated till it is equal to that of the current.

If, on the contrary, any floating body receives a motion in a contrary direction to that of the current, it will be continually retarded, till it has none, and then it will change its direction to follow that of the current.

We shall here remark, that it is indifferent whether we ascribe the motion to the solid or to the fluid; for the impression of the water upon the ship's stem is the same when under sail, as when at an anchor, provided the motion of the current be equal to that which the ship acquires by sailing.

The effort of fluids is as the square of the velocity of the current.

It is very plain that the more rapid the current is, the greater will the impression of the fluid be; for the parts will then shock the solid with greater force than when it runs slowly; so that the force is augmented in proportion to the velocity. Again, the number of the parts of the fluid that strike the solid in any space of time, is in proportion to the velocity of the current; for the faster it runs the greater will be the number of the parts that strike the solid in a space of time; so that not only the effort of the fluid, but likewise the number of parts that attack the solid, is augmented in proportion to the velocity of the current, and when these two are united, the effort of the fluid will be in a duplicate ratio of the velocity; so that if the velocity be doubled, the shock will be quadrupled.

Hence, the faster a ship goes through the water, the greater will be the resistance she meets with, and this will be augmented in a duplicate ratio of the velocity with which she sails.

The impression of a fluid increases as the surfaces which oppose its current.

It is very plain, that if one surface is double another it will receive double the number of the parts of the fluid, and of consequence the impression will be double upon the surface, whose area is double the area of another surface. Hence those ships whose midship frames have the greatest capacity meet with most resistance.

The efforts of fluids will be less when the surfaces are in an oblique position to the current, than when in a perpendicular position.

Plate

Plate IV. *Fig.* 7.] Let E A represent the course of the fluid setting perpendicularly on any body A B; it is plain, that it receives the impression of all the parts of the fluid contained between A and B; whereas, if the point B be moved to D, the parts of the water contained betwixt B and G will have no impression upon A D. Hence the quantity of the fluid which attacks A B is to that which attacks A D as A B is to A G; that is, as the radius is to the sine of the angle of incidence E A D. But if there were no other advantage gained by this oblique position, than being exposed to fewer parts of the fluid, it would be of very little service to a ship which must have a sufficient breadth, suppose A B; it is plain, the number of the parts of the fluid which give the impression will be the same, when the fore part of the ship is in the form of A D B, as when it is flat in the form of A B; but the fluid which exerts its force on the surface A D B does not produce the same impression as when it exerts its force on A B, because the direction of each particle of water, which strikes any surface obliquely, may be resolved into two directions, one perpendicular, and the other parallel to the plane.

In order to give us an idea of compound motions, and of the resolution of their forces, let us suppose two rulers A A and B B, (*Plate* IV. *Fig.* 5.) placed upon a plane at right angles to one another, and a small ball C placed at the angle of their meeting, it is plain, if we slide the ruler B B in a parallel position to itself, it will carry the ball C along the edge of the ruler A A; but if both the rulers be made to slide together, so that they still preserve the same angle, in such a manner that when the ruler A A arrives at the line VII, VII, the ruler B B arrives only at the line 3, 3. It is plain, the ball will describe the diagonal of the parallelogram C, VII, D, 3. the sides of which will be proportional to the distance the rulers have moved, that is, D, VII is to D 3 as 3 to 7; but if the rulers be supposed to be moved equally, so that when A A arrives at the line VII, VII, B B shall arrive at the line 7 7, the ball will describe the diagonal C F of the square C, VII; F 7.

Now, if we substitute any other two agents in the place of the rulers, such as two hammers, and both be supposed to strike the ball with equal force at the same time, it is plain, the ball will go in the direction of the diagonal C F; but if the force with which one hammer strikes the ball be to that by which the other hammer strikes the ball, as 7 to 3, then the ball will move in the direction of the line C D.

The principal Effects of Compound Motions. (*Plate* IV. *Fig.* 6.)

If two powers C and B act with equal force on the body A, that is to say, that the power C would drive to B in the same time that the power B would drive it to C; in the contrary directions of the lines C A and B A, the body A will remain at rest; but if one of the powers acts with greater force than the other, the body will follow the direction of that which predominates, diminished by the quantity of the smaller force.

2d, If two powers D and E act upon the body A in the same direction, viz. in the lines D A and E A, the body A will follow the direction of both, and pass through the point F, with this only difference, that it will go with greater velocity when impelled by both powers than with one.

3d, Let the two powers G and H strike the solid A, in the direction of the lines G A and H A, it will thereby receive a compound motion, the force and direction of which may be expressed by the diagonal of a parallelogram, as was before observed.

In order to construct this parallelogram, which is called the *resolution* of the forces, let the two powers G and H be supposed equal and expressed by the lines H A and G A; from the point G draw the line E G equal and parallel to H A; from the point H draw the line E H equal and parallel to G A, and the diagonal E A (the result of the two powers represented by the sides of the parallelogram H A and G A) shall express the velocity and direction of the compound motion; the effect of which will be, that the body A will be carried through the point F. But supposing the forces unequal, and let that of H, (*Fig.* 9.) represented by the line H A, be double that of G, represented by the line R A; then from the point R draw the line R S equal and parallel to H A, which shall express the force and direction of the power H; and from the point H draw the line H S parallel to R A, which will express the force and direction of the power G; the diagonal S A expresses the velocity and direction of the body A, which will pass through the point T, whereas, if the powers were equal, it would pass through the point F.

It may be remarked, that two attractive powers placed at P and Q, would produce the same effect as two impulsive powers at G and H, and that the parallelogram may be constructed on the lines A Q and A P.

CONSEQUENCES.

1st. The acuter the angle of the direction of the power is, the nearer will they approach to one direction, and act with greater force; so the result of G and H is greater than that of K and I, supposing the powers to be equal.

2d,

2d. The greatest effect of two powers is, when they both act in the same direction, and the least when they act in contrary directions.

3d. When two equal powers act in such a direction that they form an angle of 120 degrees, as A K and A I; in this and in no other case, the result will be equal to the single force of A I or A K; it only changes the direction; for when the two powers act jointly, A will be carried to F, whereas if K only acted, it would be carried to T; or if I only acted, A would be carried to V; if L only acts it will be carried to V; if M only acts it will be carried to T.

4th. If the direction of two powers make an angle less than 120 degrees, as G A and H A, they will assist one another; but if they form an angle greater than 120 degrees, as L A and A M, they will be reciprocally diminished.

The Results of a Motion impressed upon a Body A, *in Relation to a Surface* a b, *which opposes its Motion.* (Plate IV. Fig. 6.)

1st. When a body strikes a surface obliquely it will be with less force than when it strikes it perpendicularly; for it may strike it so obliquely as only to graze along it; between the perpendicular shock, which is the greatest, and the oblique, which approaches nearest to a parallel to the surface, there may be an infinite number of directions, less or more oblique, and the surface will be struck with more or less force.

2d. If the two powers are united in D, they will act, in the direction D F, with great force upon *a b*; because they not only act jointly, but likewise in a perpendicular direction upon the surface *a b*.

3d, If the two powers be equal in force, and act in the direction of the lines G A and H A, the body A will also fall perpendicularly on the surface *a b*, but with less force than in the first case, because of the obliquity of the directions.

4th. If the power H have double the force of the power G, then the direction will be changed into the line S A, (*Fig:* 9.) and the body will strike the surface obliquely in the direction of the line S T, but with less force than in the second case, not only on account of the diminution of the force of the power G, but also on account of the obliquity of the shock.

5th. It will be indifferent whether the body A receives its impulse from one single power, or from two, so that it strikes the surface *a b* in the same direction. Hence we shall have no occasion to consider the powers which give the motion, but only the velocity and the direction in which they strike the surface.

6th. It will produce the same effect, whether we change the line of direction

direction, in which the body A strikes the surface *a b*, or change the position of the surface *a b* in respect of the line of direction.

From what has been said, it will follow, that if the common effect of two powers acting upon the same body be known, and also the direction and force of one of them, then the direction and force of the other may be found; for let the body C (*Fig.* 5.) be carried to the point D by the action of two powers, and one represented by the line C, VII; draw the line D 3 equal and parallel to C, VII, and compleat the parallelogram, so shall C 3 express the force of the other power.

The Application of what has been said to the Shock of Fluids.

We have hitherto considered the shock of a solid body in different directions upon the surface of another solid, but we will readily grant that fluids do not act in the shock in the same manner that solids do. It is very probable, that when a fluid falls perpendicularly upon a surface, there is a mass of water that rests immoveable before the surface, which occupies the place of a solid body, and has nearly the same effect as if the surface was round, so that the fluid does not attack the body that opposes it in a direction perpendicular to its course; besides, the particles of water which attack a surface, whether obliquely or not, may rebound and change their direction, so that the laws of fluids are quite different from the laws of solids in the shock.

The oblique direction of a particle of water may be resolved into one that is perpendicular to the body which opposes its courses, and one that is parallel to it.

In order to construct this resolution, (*Plate* IV. *Fig.* 11.) upon the line A C inclined to the current, form the parallelogram A H E F (A E representing the velocity and direction of the current) making E F parallel to C A and E H perpendicular to C A. The diagonal E A, which represents a particle of water and its velocity, will be the result of a motion supposed to be produced by two powers, one parallel to A C, whose force and direction is represented by E F, the side of the parallelogram, and the other perpendicular to it represented by the side E H.

Hence it will follow, that when a surface is exposed to the shock of a current, in different oblique directions, the force of the direct shock is to that of the oblique, as the square of the radius is to the square of the sine of the oblique angle of incidence; for the effort of the particle E A, (which strikes the body A B, in a perpendicular direction,) is to the effort of the same particle E A; (which strikes the body A C in an oblique direction,) as as E A is to E H; but E A is to E H as A B, the sine of the right angle, is to A G, the sine of the oblique angle of incidence. But it was before observed, that the sum of the particles that strike A B is to the sum of the particles that strike A C as the radius is to the sine of the angle of incidence. Hence, by multiplying the effort of one particle, by the number of particles that strike A B, (that is, the effort of the whole water upon A B) and multiplying the effort of one particle by the number of particles that fall upon A C, that is, the effort of the whole fluid upon C A) we shall have the following proportion: The effort of the whole fluid upon A B is to its effort upon A C, as the square of the radius is to the square of the sine of the angle of incidence.

When the surfaces A B and A D, which oppose the current A E, are unequal (*Plate* IV. *Fig.* 10.) the quantities of water which strike these surfaces are as the product of the surfaces by the sines of the angles of incidence; from whence we shall have the following proportion: The effort of the fluid upon A D is to that upon A B, as the square of A G, the sine of the angle of incidence multiplied by the surface A D, is to the square of A B, the radius, multiplied by the surface A B.

CONSEQUENCES.

1st. If two equal surfaces, exposed to the same current, receive its shock in different obliquities, the impressions will be to one another as the squares of the sines of the angle of incidence.

2d. A surface parallel to the current can receive no shock, because there is no angle of incidence.

3d. If two unequal surfaces are exposed to the same current, the impressions they receive by the shock in different obliquities, are to one another as the products of the squares of the sines of the angles of incidence, and of the surfaces that receive the shock.

4th. If two equal surfaces receive the shock of two unequal currents, the impressions will be to one another as the products of the squares of the velocities, and of the squares of the angles of incidence.

5th. If two unequal surfaces are exposed to two unequal currents, which strike them with different obliquities, the impressions will be to one another as the products of the squares of their velocities; of the squares of the sines; of the angles of incidence; and of the surfaces.

All these consequences may be deduced from the preceding principles; it only remains to apply them

Let A B (*Plate* IV. *Fig.* 4.) represent the extreme breadth of a vessel, and let the fore part be formed according to the angles A C B,

or

or A F B, or A L B. In order to find the efforts of the fluid, supposing the velocity and direction to be the same, and parallel to the keel, in the three cases, upon the middle of the line A B, erect the perpendicular E L, which will pass through the tops of all the triangles; then to find the sines of the angles of incidence, with the radius A B describe two arches, A F and B F, to intersect one another in the vertex of the equilateral triangle; the arches will intersect the sides of the angle, that is less than 60 degrees; but not the sides of that which is more than 60 degrees; produce one of the sides from C to M (*Plate* IV. *Fig.* 4.) Lastly, let fall the perpendiculars M D, F E, P K, upon the line A B, from all the points where the arches intersect either the sides of the triangles, or the sides that are produced; so shall A E, A D, and A K, represent the sines of the angles of incidence upon the different triangles A F B, A C B, and A L B.

It will be easy to observe, that the effort of the fluid upon the intire fore parts A C B, A F B, or A L B, is to the effort upon the extreme breadth, as the effort upon A C, A F, or A L, is to the effort upon A E; but it was proved before, that the impressions received by two unequal surfaces, opposed to the direction of a current, are as the squares of the sines of the angles of incidence multiplied by the surfaces; so, in this case, the impression on A C will be to that on A E, (or, which is the same thing, the impression on A C B will be to that on A B) as the square of A D, the sine of the angle of incidence, multiplied by A C B, is to the square of the radius multiplied by A B.

We have also the effort on A F B to the effort on A B; as A F B, multiplied by the square of A E, the sine of the angle of incidence, is to A B, multiplied by the square of A B the radius. This proportion would shew the effort of the fluid upon the prow A F B, in a perpendicular direction to the sides A F and B F, which would be very useful, if it were required to determine the dimensions of the timber that is to resist that pressure of water; but in the present case, where only the relative effort upon the prow is considered in the direction of the keel, we must form another resolution. Let then C D (*Fig.* 8.) represent the effort upon F B, perpendicular to that surface; if from the point D we let fall the perpendicular D H, and compleat the parallelogram G C D H, C G shall represent the relative effort upon the prow in the direction of the keel, so the whole effort upon F B, may be represented by F B multiplied by the square of the angle of incidence, which is to the relative effort as F B is to E B: The relative effort then is equal to the square of the sine of the angle of incidence multiplied by E B, or by the sum of the particles which fall upon F B; so to find the relative effort on F B, we must multiply

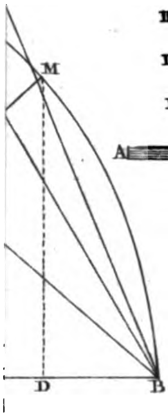


Fig. 5.

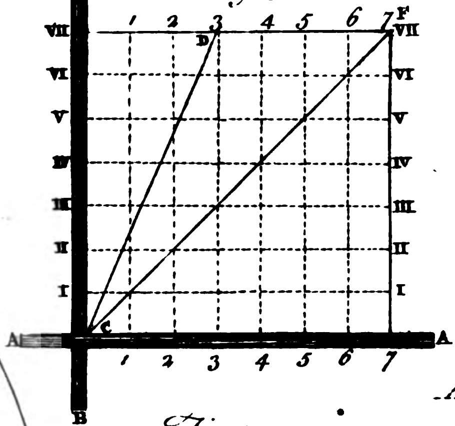


Fig. 6

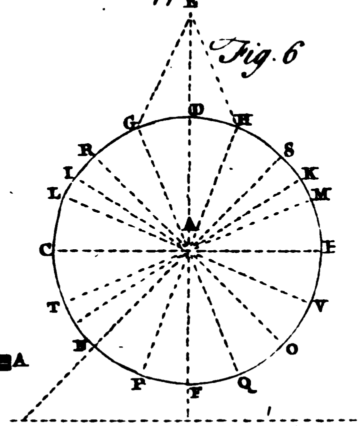
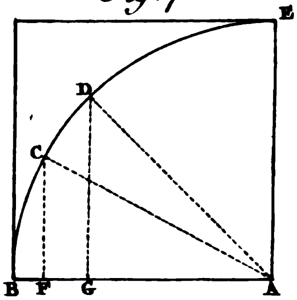


Fig. 7.



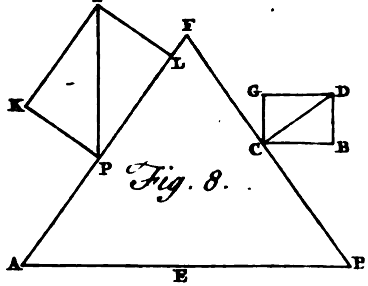


Fig. 8.

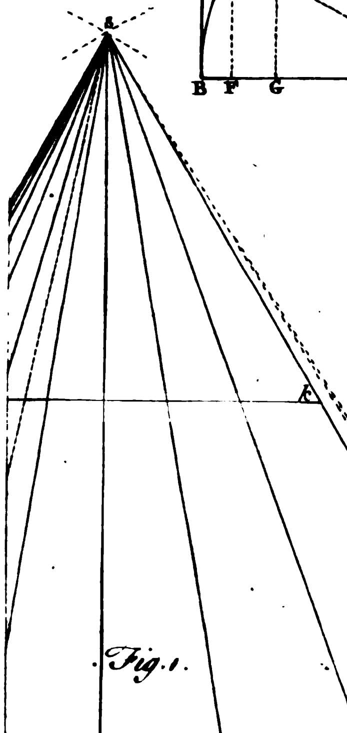
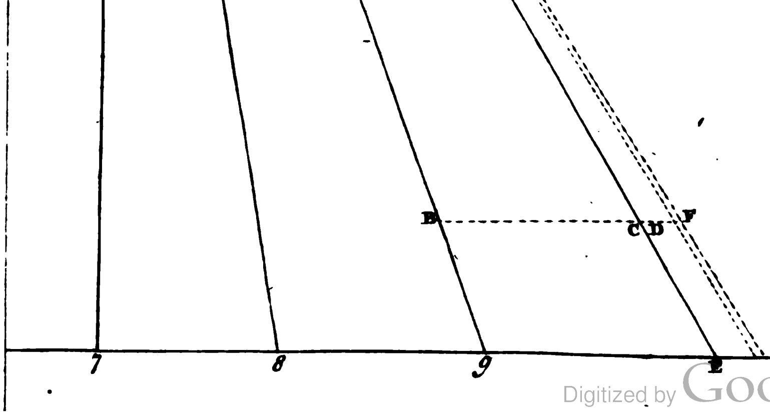



Fig. 1.

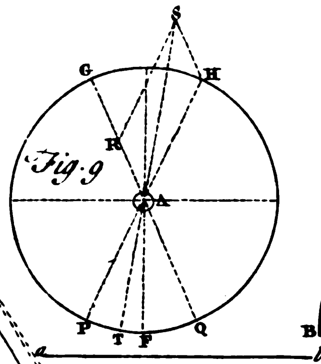


Fig. 9

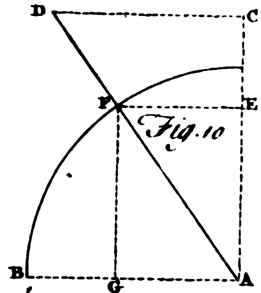


Fig. 10

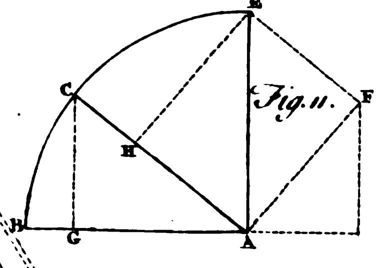


Fig. 11.

multiply the square of the angle of incidence by the projection of the plane F B upon the beam E B.

Tho' this method cannot be truly applied but to rectilineal triangles, yet, by dividing curves into a number of small parts, each may be considered, without any sensible error, as a strait line. M. *Bouguer* makes use of this method of approximation to a sufficient degree of exactness. What we have already said upon that head, it is to be hoped, will facilitate this description to such as have only a slight knowledge of the mathematics; so that all that remains now is, to apply this to the draught of a ship of 70 guns, which has been already laid down.

A Calculation of the Resistance of a Fluid upon the Prow of a Ship of 70 Guns, which we have laid down in a Draught, compared with the Effort of the same Fluid upon the Area of the Midship Frame.

As the operations are to be performed upon the plane of projection before laid down, all the frames in the fore part must be exactly formed as before in *Plate* II. in order to which it will be necessary to make use of a larger scale, as in *Plate* V.

It will be very convenient to draw the water lines I, II, III, &c. and the frames 1, 2, 3, &c. to the midship frame, at equal distances from one another.

It is plain, that the water lines and frames divide the prow into trapezia, such as *r a*, 8 *b*, 7 *c*, &c. corresponding to the trapezium A D, and parallelogram *a d*, in the plane of elevation, *Plate* II.

It will be necessary to observe, that there must be so many water lines and frames, that the lines 8 *a*, 7 *b*, 6 *c*, &c. which are curves, may be esteemed strait lines.

We must draw the diagonals *r a*, 8 *b*, 7 *c*, &c. through the trapezia; but we may take two trapezia at once near to the midships, because the ships sides are there nearly parallel to the current.

It will likewise be proper to observe, that these diagonals are the projections of the diagonals of the parallelograms represented upon the plane of elevation, at least, on the surface of the ship; as for instance, the diagonal 8 *b*, on the plane of the projection, is the projection of the diagonal 8 *d* drawn on the plane of elevation.

These diagonals divide the prow into the triangles 1, 2, 3, 4, &c. which strike the fluid with different degrees of obliquity.

We have not the entire areas of these triangles, by reason of the curving of the prow, but only their projection on the midship frame; but this is all we want; for the sum of all the particles of water that strike the triangles

angles are proportioned to the triangle projected on the midship frame, since the water that ranges along each triangle may be considered as a triangular prism, the base of which is equal to the triangle *r a* 8, *Fig.* 1. *Plate* V. and this was the thing in question. M. *Bouguer* proposes to calculate the effort of the fluid on each triangle, their sum will give the shock of the water upon the whole prow, and compare this to the shock of the fluid upon a surface parallel to the area of the midship frame.

To attain this, M. *Bouguer* lets fall perpendiculars to every frame, from the angles formed at the intersection of the water lines and the diagonals that were drawn to form the triangle; for instance, upon the frame 8, the perpendiculars *l b* and *r p*; upon the frame 7 8, the perpendicular 8 *m* on one side, and the perpendicular *n c* on the other side, &c.

This method requires that there be as many right angled triangles formed as there are triangles on the prow; and as there must be a great number of them, it will be necessary to find some method of forming them. The following seems to me to be the most expeditious.

Draw two parallel lines, B D and C R; let the distance betwixt them be equal to that betwixt the frames on the plane of elevation, and by this one operation we have the height of all the triangles that are contained betwixt the parallels.

As the base of all the rectangles should be equal to the perpendicular of the corresponding triangle of the prow, we may set off the length of each perpendicular upon the parallel C R; so shall C H, *Fig.* 2, be equal to *r p*, *Fig.* 1; H L, *Fig.* 2, equal to *s a*, *Fig.* 1; L E equal to 8 M, &c. To compleat the triangles, draw the perpendiculars H N, L M, and the hypothenuses D H, N L, &c.

If one of these rectangles be considered singly, D H may represent the radius, and C H will be the sine of the angle of incidence.

All these triangles being described, we may begin to find their areas on the plane of the projection, because it is upon this that the relative impulse in the direction of the keel depends; which is the thing now required, as was before observed.

The surface of a triangle is found by multiplying half the base by the perpendicular; so the surface of the triangle *r*, *a*, 8, will be the product of the perpendicular *r p*, (equal to C H) multiplied by half the base *a* 8, and this will be the sum of all the particles which strike the triangle *r*, *a*, 8, which is an element of the prow of the ship.

In order to find the relative force of the fluid in the direction of the keel on that part of the bottom corresponding to the triangle *r*, *a*, 8, it is only

only multiplying the surface of the triangle by the square of the sine of the incidence; in place of multiplying it by the square of the radius, which would give the impulse the triangle would receive from the water in a perpendicular direction; now if we divide this impulse by the oblique one, the quotient will give the quantity that the impulse is diminished by the obliquity of the prow; but there will be no occasion for this last step, for as the sum of all the products of the triangles multiplied by the square of the radius, gives the effort of the fluid upon the midship frame; the direct effort may be found by multiplying the area of the midship frame by the square of the radius, and if this be divided by the sum of the products of all the triangles, multiplied by the squares of the sines of the angles of incidence on each triangle, we shall know the diminution of the resistance which the prow meets with in proportion to that of the midship frame.

It would be almost impracticable to multiply the surface of each triangle by the square of the sine of the angle of incidence, upon which account M. *Bouguer* substituted proportional lines in place of the squares of the sines, which we shall now explain.

It was before observed, that if D H be the radius, C H will be the sine of the angle of incidence.

If we let fall the perpendicular C O upon the line D H, we shall have the triangle D C H similar to D O C; so taking the equal lines C D, and N H for the radius, C O will be the sine of the angle of incidence.

If we draw O P perpendicular to D C, the triangles D O C and C O P will be similar, therefore the triangles D C H and C O P will be similar, and D H is to C H as O C to C P; but D H is to C H as D C to C O, and by multiplying these two proportions, the square of D H will be to the square C H as D C is to P C; that is, if D C represent the square of the radius, P C will be the square of the sine of the angle of incidence C D H. So the lines C P, H Q, L G, &c. give the squares of the sines of the angles of incidence in the triangles 1, 2, 3, &c. which are to be multiplied by the surfaces of the triangles; and the parallels D C, N H, &c. always represent the radius.

A Cal-

A Calculation of the Refiſtance of the Fluïd upon the Prow of a Ship of 70 Guns, compared with that upon the Midſhip Frame.

Triangles.	Perpendicular.			Multiplyed by half the baſe.			Product.				Multiplyed by the ſquare of the ſine of the angle of incidence.			Product gives the effort of the water upon the triangle.			
1ſt.	f.	in.	lin.	f.	in.	lin.	f.	in.	lin.	poi.	f.	in.	lin.	f.	in.	lin.	poi.
1	6	6	0	1	9	6	11	7	9	0	3	2	0	36	10	6	6
2	5	7	6	1	6	3	8	6	7	10	2	8	0	22	9	9	0
3	4	6	6	1	9	6	8	1	7	9	1	11	6	15	11	2	8
4	4	6	6	1	9	6	8	1	7	9	1	11	6	15	11	2	8
5	2	9	6	1	8	6	4	9	2	9	0	11	0	4	4	5	6
6	2	8	0	1	9	6	4	9	4	0	0	9	0	3	7	0	0
7	1	11	6	1	7	6	3	2	2	3	0	5	0	1	3	10	11
8	2	2	0	1	9	0	3	9	6	0	0	6	6	2	0	7	9
9	1	4	0	1	7	6	2	2	0	0	0	2	6	0	5	5	0
10	1	4	0	1	7	6	2	2	0	0	0	2	6	0	5	5	0
11	0	5	0	1	6	6	0	7	8	6	0	1	0	0	0	7	8
12	0	10	0	1	7	6	1	4	3	0	0	2	0	0	2	8	6
13	0	2	6	1	6	6	0	3	10	3	0	0	8	0	0	2	6
14	0	4	0	1	6	6	0	6	2	0	0	1	2	0	0	7	2
15	0	1	0	1	6	6	0	1	6	6	0	0	3	0	0	0	4
16	0	5	0	1	6	6	0	7	8	6	0	1	6	0	0	11	6

The total effort of the firſt piece *r* V	104	2	8	8
Of the ſecond	57	10	6	2
Of the third	43	8	6	5
Of the fourth	28	0	8	10
Of the fifth	12	9	8	7
Of the ſixth	3	2	8	11
Total	249	10	11	7

We muſt in the next place find the direct effort of the water upon the area of the midſhip frame, by multiplying the area by the ſquare of the radius.

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OPERATION.

Half the 6th water line *r* VI	10	2	0
The whole 5th water line V	20	0	0
The 4th water line	19	5	0
The 3d water line	18	1	0
The 2d water line	15	11	6
The 1st water line	12	0	0
The breadth of the keel	0	0	0
Total	95	9	6
Multiplied by the distance betwixt the water lines, which is	3	2	0
Product is the area of the midship frame	303	4	1
Multiplied by the distance betwixt the frames	8	0	0
Product	2426	8	8

This being divided by 249 : 10 : 11, the sum of the efforts of the fluid upon the triangles of the prow; the quotient is 9 $\frac{7}{10}$, which shews that the effort of the fluid upon the prow is to that upon the midship frame as 1 is to 9 $\frac{7}{10}$, which is a sufficient diminution of the resistance for a ship of this force. Hence we may conclude that the water lines in the fore-body are well formed, but a frigate will require more diminution, as will appear by the following examples.

The *Brillant*, as 3 $\frac{1}{2}$ to 1, a very bad sailer.

The *Tigre*, as 5 to 1, a company keeper.

A ship of 50 guns, designed by M. *Boyer*, but not built, as 8 to 1.

The *Monarque*, of 74 guns, 4 lb. shot, built by M. *Ollivier* in 1744, as 13 $\frac{1}{2}$ to 1.

The *Alcide*, of 64 guns, by M. *Ollivier*, at *Brest* 1741, as 6 $\frac{1}{4}$ to 1.

The *Renomme*, built at *Brest* by M. *Desalieurs* 1744, as 10 to 1.—This ship, by the account of the captain, was a very fine sailer.

The *Badine*, 6 guns of 3 lb. shot, as 7 $\frac{1}{4}$ to 1.

The *Panthere*, of 20 guns 6 lb. shot, as 10 $\frac{1}{2}$ to 1.

The *Amazon*, of 44 guns, built by M. *Blase Pengalot*, as 8 $\frac{3}{5}$ to 1.

The *Superbe*, built by M. *Helie*, as 5 $\frac{2}{10}$ to 1.

The *Mutine*, of 24 guns, built by M. *Geffroi*, senior, as 10 $\frac{3}{5}$ to 1.

We have compared the efforts of the fluid upon the prow of each ship, with that upon the plane, equal to the area of the midship frame.

It will be proper also to examine if the resistance in those be less than in ships which are known to be good sailers; but it may happen that a ſhip, whoſe midſhip frame has a ſmall area, may meet with little reſiſtance, tho' her prow be not diminiſhed in proportion to that of her midſhip frame; ſo it will not be ſufficient to know this proportion only, to be aſſured whether or not the ſhip will be a fine ſailer. We muſt alſo compare the areas of the midſhip frames, and not reſt ſatisfied with comparing the efforts of the fluid, upon the prow of the ſhip we have laid down, with that upon the prow of the ſhip of the ſame rate, which has gained a good character.

The firſt Example of Compariſon.

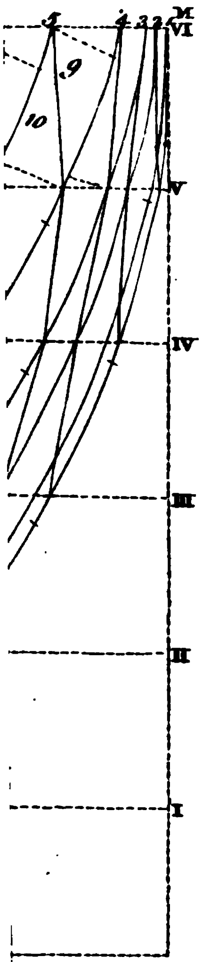
We know that the area of the midſhip frame of the 70 gun-ſhip, we have laid down, is 606 : 8 : 2, and that the effort of the fluid upon the prow is to that on the midſhip frame as 1 is to 9 $\frac{7}{10}$. Now if another ſhip of the ſame rate has the area of her midſhip frame 7 or 800 feet, ſuppoſing the ſails, and every thing that may contribute to ſailing, to be alike in both; its plain this laſt cannot ſail ſo well as that we have laid down, and by this example, it is very plain, that if we would calculate which of two ſhips would ſail beſt, we muſt, after finding how much the reſiſtance of the fluid upon the midſhip frame of each is diminiſhed by the form of their prows; alſo compare the areas of their miſhip frames, that we may know which of the two has the greateſt maſs of water to diſplace; but if it was only required to know, which of two ſhips of the ſame rate would ſail beſt, it would be ſufficient to compare the efforts of fluids upon their prows.

The ſecond Example of Compariſon.

We have found by the calculation, that the effort of the fluid upon the prow of our ſhip of 70 guns, is 249 : 10 : 11 : 7; but if, by a like calculation, we find the reſiſtance upon the prow of a ſhip of the ſame force, and carrying the ſame quantity of ſail, to be 300 feet, we may thence conclude that ours will ſail beſt.

It will alſo be proper to examine, by the ſame calculation, whether the ſhip we have laid down, can carry a good ſail, drive but little to the leeward, and ſteer well.

F I N I S.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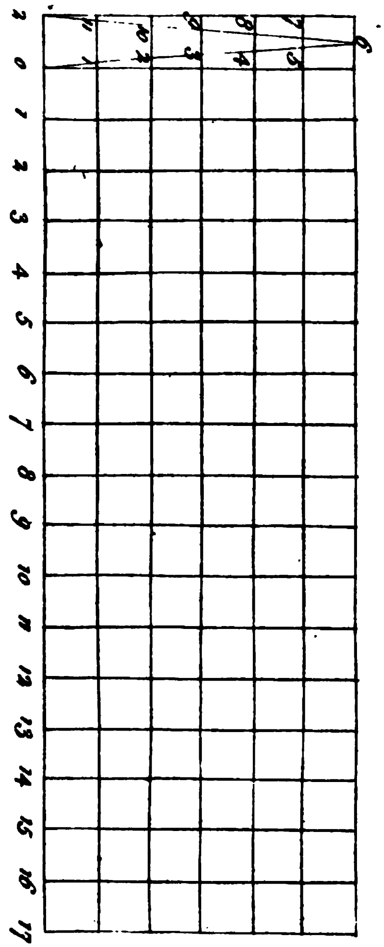
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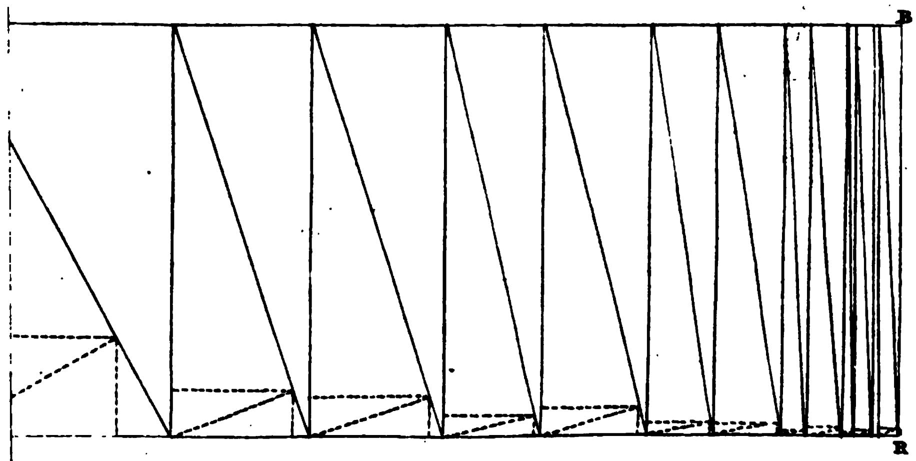
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SUPPLEMENT
TO THE
TREATISE on SHIP-BUILDING.
CONTAINING
EXTRACTS
TRANSLATED FROM
M. BOUGUER's *Traité du Navire.*
TOGETHER WITH
M. DUHAMEL's Method of finding the Center of Gravity.
And ſome Occaſional REMARKS.

ALSO

An Account of ſeveral EXPERIMENTS, made to aſcertain the FORM of a SOLID that will move with the greateſt Velocity through the Water.

LIKEWISE

A Method to determine the Thickneſs of the Plank, in the Direction of the Planes of the Timbers.

With the Proportions for MASTS, YARDS, CAPS, &c.

By MUNGO MURRAY.

LONDON:
Printed for A. MILLAR, in the *Strand.*
MDCCLXV.

PREFACE.

IN grateful acknowledgment to the public, for their favourable reception of my firſt Edition, I have, in this Supplement, collected all the diſcoveries I could either make by my own obſervations, or gather from the writings of M. BOUGUER and M. DUHAMEL.

I have likewiſe endeavoured to determine the thickneſs of the plank in the direction of the planes of the timbers, and have illuſtrated it with a Plate engraved for that purpoſe; Plate V. in the firſt edition, being too much crowded with lines, to admit of any addition.

Alſo an account of experiments that have been made to aſcertain the form of a ſolid that will move through the water with the greateſt velocity. Theſe experiments likewiſe ſerve to determine the propereſt poſition of the midſhip frame.

The proportions for maſts and yards, caps, tops, truſſeltrees, and croſs-trees, are inſerted.

Likewiſe the weights of the anchors, the dimenſions of the cables, the number, nature, length, and weight of the guns on each deck, according to the rates of the ſeveral ſhips in his Majeſty's Navy.

CON-

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Of the Progreſs of Ship-building in *France*.

Extracts from M. Bouguer's *Traité du Navire*.

M. Bou-

To

Dimensions of the Masts and Yards.

SUPPLEMENT

TO THE

PRACTICAL TREATISE

ON

SHIP-BUILDING.

M. BOUGUER, in the Preface to his TRAITE DU NAVIRE, gives an account of the progreſs of ſhip-building in *France*, with the names of ſeveral eminent men who applied themſelves, with much zeal, to reduce naval architecture to certain mathematical principles; and ſays, that at a conference held at *Paris* in 1681, the principal dimenſions uſed in *France* were eſtabliſhed by an order of the arſenal. He makes mention of *Pierre Janſſe Horn*, who, in the beginning of the laſt century, imagined that *Noah*'s ark ſhould be made the ſtandard and pattern of the form of a ſhip: But M. *Bouguer* obſerves, he did not conſider that the ark, far from being deſigned to ſail with any degree of velocity, was built only to ſuſtain a great weight, when lying at reſt on the ſurface of the waters of the deluge. Be that as it will, it ſeems, at leaſt probable, that the firſt deſign of building floating veſſels, was to carry goods from one place to another.

Now, the propereſt veſſels for that purpoſe would be ſuch as could contain the greateſt quantity of goods, and carry them in the ſhorteſt time to the intended port: So that capacity and velocity ſeem to be two eſſential qualifications.

As to the firſt, that of capacity, a circle has a greater area than any other plain ſurface of the ſame circumference; and, conſequently, a cylindrical tub would be the propereſt form to anſwer the firſt end, but the very worſt for the ſecond, *viz.* that of velocity: For, by what method ſoever the power that ſets the veſſel in motion is to be applied, it is indifferent what point goes foremoſt; and if it were applied in an oppoſite direction, the vessel would go as fast a-stern as a-head, if I may be allowed that expression, where there is neither head nor stern.

A Cube is the next solid of greatest capacity; but this is subject to the same inconveniencies as the Cylinder: Hence we may conclude, that all floating vessels may be longer than broad.

An oblong rectangular parallelopiped will go with greater velocity endways than sideways; but it will be indifferent which end goes foremost; and, besides, this form would meet with great resistance in passing through the water. For, let the component parts of that fluid be supposed never so small particles of a globular form, it is certain they must have some kind of cohesion; and tho' they are easily set in motion, they must actually be separated before any body can pass through them; and any plane moving in a direction perpendicular to itself, must displace as many of these particles as are contained in the area of that plane; and, as it advances forwards, will still have the same number of particles to displace, before it can go a-head; hence we may conclude, the parallelopiped will not answer the two essential properties.

Let us next examine, how far the wedge would answer those purposes: This being tapered to an edge at the fore-end, will easily divide the fluid, and the sides will attack the particles in an oblique direction, and consequently will meet with less resistance in passing through the water. If the particles of water were as closely united as those of wood, perhaps the wedge would be the properest form to force its way through a body of water. But it must be observed, that the wedge acts in a quite different manner, when cleaving a tree, and when dividing a fluid; for the parts that unite the tree are separated at a great distance before the wedge, and the parts through which it has passed are so far from endeavouring to unite themselves again, that the extremity of the tree will be double its diameter asunder, before the wedge has advanced near the other end; whereas, the wedge has no sooner passed through the particles of water, but they immediately unite as close as before, and none of the particles are separated till the wedge actually strikes them, and no sooner has the wedge forced its way through any number, but it has the same number to encounter, and drags a quantity of what is called dead water after it: for, placing a flat piece of wood in the water, at the after end of the wedge, it will keep close to it, till the wedge alters its direction; for which reason, there seems to be a necessity for tapering the after-end of the wedge. It must likewise be observed, that the mall that forces the wedge a-head drives it in a direction perpendicular to the after-end; whereas the wind that forces a ship a-head, sometimes strikes it in a direction

direction oblique to the keel, which will be apt to drive it out of the direction of the keel, as is the case of a ſhip that loſes her rudder: This is another reaſon for tapering a ſhip at the after-end, for otherwiſe the rudder would have but very little power to keep her ſteady in a ſtrait courſe.

We have now found, that all ſhips muſt be longer than they are broad, and likewiſe tapered at each end: The next thing to be conſidered is, whether or no the ſides ſhould be perpendicular to the bottom: In that caſe, all vertical ſections perpendicular to the keel, and at right angles, would be parallelograms, which would be a very improper form for dividing a fluid; for though, by the tapering at the fore end, the reſiſtance would be leſſened, yet the particles ſhould be ſo far ſeparated as to allow the plane of the midſhip frame to paſs through them; and though the effort of the fluid upon the midſhip frame would be greatly diminiſhed by its oblique direction, yet as the ſhip would then be as broad at the keel as at the water's edge, the bow would meet with great reſiſtance every time the ſhip went about; ſo that there ſeems to be a neceſſity, not only of tapering them at each end, but likewiſe from the extreme breadth down to the keel.

The next enquiry muſt be, whether theſe vertical ſections are to be limited with curve or ſtrait lines, and how to aſcertain their form.

The mathematicians have endeavoured to inveſtigate the form of that ſolid which meets with leaſt reſiſtance in paſſing through the water; but they have not drawn any practicable rules from thence, to determine the form of a ſhip; and ſhould they be ſo lucky, after a tedious calculation, as to find out the particular form of ſuch a ſolid, it would be of little uſe in forming the body of a ſhip: For it is ſuppoſed, that the ſolid is to continue in the ſame poſition in the water, otherwiſe the immerged part will alter its form as often as it alters its poſition, unleſs it be, as M. *Bouguer* would have it, formed by the revolution of a curve round its axis. Hence we may conclude, that the particular form of a ſhip cannot be determined by rules that will admit of a mathematical demonſtration.

The builders, finding they could have very little aſſiſtance from the mathematicians, have applied themſelves to experience; and though they have not found any particular form which may be a ſtandard for all ſhips of the ſame burthen, and deſigned for the ſame ſervice, yet in ſome points they ſeem to agree. Hence it is, that, in ſhips of war, of the ſame rate, the principal dimenſions are nearly the ſame; and in all ſhips the midſhip frame is nearer the fore-part than the after-part. For, finding by repeated trials, that a maſt or tree, when tapered, will tow faſter through the water with the butt end foremoſt than with the ſmall end, they conclude it will be ſo in ſhips; though M. *Bouguer* thinks the only reaſon for towing the butt end foremoſt is, that the rope may not ſlip. The rules given us by M. *Bouguer*, for calculating the reſiſtance, ſeem to be deduced from the ſame principles as thoſe for aſcertaining what weight will raiſe any heavy body on an inclined plane, which may be effected with as great certainty as by weights in a pair of ſcales, as is proved by experiments.

If the particles that compoſe a maſs of fluid were ſolids of ſuch a particular quality, that when once ſeparated, they could not be united again, without the application of ſome exterior force, the ſame rules might anſwer in both caſes. But when it is conſidered that the particles of the fluid have a natural energy, whereby they unite themſelves as ſoon as the force that ſeparated them is removed, we may hence conclude that every particle has two motions, the one parallel, and the other perpendicular to the axis of the maſt. If the maſt were at an anchor, floating on the water, and a current ſetting parallel to its axis, the ſhock ſuſtained by the maſt would be the ſame as if the maſt were in motion, (with a velocity equal to that of the current) and the current at reſt. It ſeems probable, that the natural tendency the particles have to unite themſelves, will as it were graſp the maſt, and retard its motion, when the ſmall end is foremoſt; whereas, when the butt end is foremoſt, and hath once opened a paſſage, the particles, by their union, will rather force it a-head, or at leaſt prevent its going a-ſtern; and experience ſeems to favour theſe principles; otherwiſe a ſhip would go faſteſt ſtern foremoſt. M. *Bouguer* tells us, the reaſon for making ſhips fuller before than abaft, is, not to make them go with greater velocity through the water; for, he ſays, that would have a quite contrary effect, but to make them ſteer well.

Since capacity is an eſſential quality, the immerged part muſt be of ſuch a form as to be able to ſuſtain the whole weight of the ſhip compleatly rigged, with guns, ammunition, proviſions, ſtores, *&c.* The weight of all ſhips of war, of every rate, is now pretty well known; ſo that we may find, by calculation, if the load-water line be properly placed: But this is not all that is to be conſidered; great regard muſt be had to the velocity, ſtability, property of ſteering well, carrying ſail, and many other neceſſary and ſeemingly oppoſite qualities. How to attain all theſe qualities has been attempted by ſeveral eminent mathematicians and builders, who, inſtead of determining any particular form, have produced as many different, and ſeemingly directly contrary rules, as there are different complexions and ſtatures among the projectors.

The mathematicians have given certain rules for finding the center of gravity, both of the ſhip when properly loaded, and alſo the center of gravity of the column of water ſhe diſplaces, M. *Bouguer* likewiſe gives directions how to ſtow the goods, ſo that the center of gravity may be properly placed with reſpect to the *metacenter* and the center of gravity of the column of diſplaced water; which laſt cannot be altered after the ſhip is built. It is on the proper ſituation of theſe that the ſtability of the ſhip depends. As to velocity, they have given us rules for calculating the reſiſtance of the fluid on the fore part of the ſhip: but unleſs it can be proved that the velocities are always proportional to the reſiſtances, it ſeems we ſhall gain little by this; as there is no account taken of the after body, and in the calculations they ſuppoſe the ſhip to be upright, and ſailing in the direction of the keel; whereas a ſhip often lays her ſcuppers in the water, when cloſe hauled on a wind, and ſometimes makes two or three points lee way, ſeldom leſs than one; and yet ſome ſhips in ſmooth water will then ſail within two or three knots as faſt as when going large. We may venture to aſſert, there will be no proportion betwixt the velocities, and reſiſtances in theſe two caſes; for in the firſt all the particles that ſtrike the fore part looſe their power as ſoon as they paſs the midſhip frame; afterwards, according to his principles, they occaſion no reſiſtance; whereas, in the ſecond, every particle has its full force, acting on the whole length of the ſide, and the area of the ſection, which in this laſt caſe would receive the perpendicular ſhock, would be almoſt double that of the midſhip frame; add to all this that there is room to ſuſpect theſe rules of being deduced from wrong principles, as was before obſerved. But admitting all this, and that the velocities may be calculated, after the ſhip is built, and found even by experience to be proportionate to the reſiſtances, what will that avail us, if we have no inſtructions how to form the body ſo, as to be capable of the greateſt velocity, in all poſitions, conſiſtent with the requiſite capacity, ſtability, &c? There are other very material points to be conſidered, ſuch as the center of rotation, or the axis on which the ſhip turns when ſhe inclines to one ſide, when ſhe tacks or pitches; theſe are continually ſhifting, as is the point of ſuſtentation or ſuſpenſion.

In all branches of the mathematical ſciences, there are certain theorems demonſtrated, from whence the practical rules for the ſolution of various problems are deduced, in which there are always ſome neceſſary *data* given, by which the unknown things may be diſcovered.

It

It is to be wished we could proceed in the same manner, and with the same certainty, in ship-building; but I do not find that any who have treated that subject have given us any invariable rules for settling these points; and indeed, considering the infinite number of properties, and in some cases so opposite to one another, that if any of them be pursued to too great a degree, it will destroy another very essential quality. I say considering all these things, it will be a very difficult task, if not impossible, to unite them all in one body; add to this that the different seas, and different services in which they are to be employed, will require as different forms; so that theory alone, without actual experiment, seems insufficient to reduce this complicated art to a regular system. I shall just mention some of the necessary *data*.

1st. The whole weight of the ship compleatly rigged and boarded.

This is generally given, both in ships of war, and in those for the merchant service, being what is generally understood by tuns; that is, builder's tuns; but the true tunnage of most ships of war is now pretty well known, as the number and weight of the guns, provisions, &c. of each rate is established.

2d. The length of the gun deck.

This in ships of war may be nearly determined by the number of guns.

3d. The breadth.

If the section of the load-water line were a regular curve, the length would determine this, and its area might be calculated; and converting the whole weight into cubick feet of salt water, and dividing those by the area of the load-water line, we should have the depth or draught of water; that is, supposing the form of the body to be that of a bathing tub, which perhaps would be very proper for carrying goods in a canal, where it might be dragged by horses; but as ships are to encounter high seas, and sustain the violence of storms of wind, it is plain they will require a quite different form.

4th. The depth of the hold, and draught of the water fore and aft.

5th. The extreme breadth of three sections at right angles to the keel, and perpendicular to the plain of flotation; and likewise the extreme heights of these breadths, together with the breadths and heights of the top-timbers of these sections; one of them to be near the middle, another at the after end of the keel, and the third at the beak head.

6th. The rake of the post and stem.

7th. The situation and exact form of the midship frame and likewise of the other two vertical sections; and if to these three we add the other two

two which M. *Duhamel* calls the balance frames we may safely say the whole form of the ship is determined.

The great difficulty will be to obtain these *data*. M. *Bouguer*, and after him M. *Duhamel*, hath pursued this subject as far as the nature of theory is capable; from whence they have deduced several useful practical inferences, but have still left these points undetermined, and at last refer us to the general practice of the most experienced builders. So that what improvements have been hitherto made seem chiefly owing to experience; and some think it highly probable that the form which comes nearest nature, such as that of the swiftest fishes, will best answer the purposes of shipping. But here we shall find ourselves very much embarrassed; for fishes are wholly immerged, and the force that moves them is wholly in their own power, and they are in no danger of being drove out of their intended course by an external force, the author of nature having furnished them with every thing that is necessary, either for pursuing their prey in a direct course, or turning themselves as occasion requires; whereas in a ship, it is quite otherwise, as she is entirely subject to an external force, and governed by the helm; and therefore her form must be such as may be most capable of receiving these impressions, and what nature has denied her, must be supplied by art.

As all who have written on this subject have left these points undetermined, I shall not attempt it. I have in the appendix to the first edition abridged the substance of what M. *Duhamel* has said in his treatise, and in this Supplement shall extract some of M. *Bouguer*'s fundamental principles, together with what M. *Duhamel* has advanced on the center of gravity in his second edition; which I shall endeavour to translate so as to be intelligible to those who do not understand the *French* language, and, as occasion offers, make such remarks of my own as I think necessary.

EXTRACTS

EXTRACTS

FROM

M. BOUGUER's *Traité du Navire.*

M. BOUGUER divides his Treatiſe into three books, the firſt of which contains a general idea of the conſtruction of ſhips, and divers remarks on the common rules, in three ſections.

In the firſt ſection, which he divides into twelve chapters, he defines the names of the different pieces that form a ſhip, and their proportions, according to the practice of the moſt eminent builders; and likewiſe deſcribes the various methods uſed by them in forming the timbers. This takes up the firſt nine chapters; for which we refer to M. *Duhamel*, who has given us the ſubſtance of what M. *Bouguer* has ſaid on thoſe heads, as tranſlated in the Appendix.

In the 10th and 11th chapters, M. *Bouguer* makes ſome remarks on the form which the common rules gives to a ſhip, and by what methods they may be amended.

It would be needleſs, ſays he, to give any further account of the ſeveral methods uſed by builders to form the figure of their ſhips, and project the frames; but it ſeems that all theſe prove, beyond diſpute, that they have not yet found out a fixed rule. The only reaſon why they have uſed ſo many different methods, is, becauſe they could not find the beſt. It would have tended much more to the advantage of their art, if they had in practice kept by one general rule, and only changed ſome particular circumſtances, carefully remarking the reſult of ſuch a change.

Experience would have proved the beſt means of bringing naval architecture to perfection, if the thing had been poſſible; but it is plain, that practice alone is inſufficient in many caſes; for, though ſome points may be determined thereby, yet, with reſpect to many others, it ſtands in need of theory. As nothing but a ſincere deſire of finding the truth, has engaged us in theſe reſearches, we ſhall not fail to take proper notice of what is good in the common rules, and ſhall ſupport them by all the arguments that may occur to us. I imagine the midſhip frame might be carried further forward, and placed, not at $\frac{5}{12}$ of the keel, but at $\frac{5}{12}$ of the length of the immerged part, or even a little nearer the head. Thus it would always be nearer the fore part than the after part; the fore part would be fuller than the after part, and the immerged part would have more of the form of a fiſh.

It is well known, that the extreme breadth of every frame is higher abaft and afore than in the midſhips, but more on the aft part, which will make the ſhip draw more water abaft than afore, about one ſixth part of the depth of the hold. As the fore part cannot ſo readily divide the water, when the keel is perfectly level, as when it is inclined to the ſtern, it being uncertain what property to aſcribe to it, the moſt eligible method would, doubtleſs, be to try the reſult at ſea, and make choice of what experience indicates.

Seamen, no doubt, tried to find her beſt ſailing trim when at ſea; and having frequently remarked, that it was neceſſary to make her draw more water abaft than before, they eſtabliſhed it as a law, by obſerving it; whereby we ſhall at leaſt gain this advantage, that the ſhip will anſwer her helm better. This will occaſion the decks not to lie parallel to the keel; for, admitting they may be of the ſame height afore, that they are in midſhips, they are raiſed conſiderably higher at the poſt, about the ſixth part of the depth of the hold.

Now, taking what we have ſaid for granted, the builders, after all their trials, are very far from having found out the true figure of the bow, from whence almoſt the whole of the round ſhould be taken away.

The decks being fixed will determine the height of the beams; ſo the decks will be no where ſo high as the extreme breadth of the frames, but in midſhips. There is another important reaſon for raiſing the breadth higher afore than abaft, though few attend to it. When a ſhip is cloſe hauled by the wind, and lays much over the weather ſide, it will loſe much of the breadth; whereas, on the contrary, the lee ſide will gain conſiderably. The ſhip then diſplaces a great deal more water on the lee ſide, and, according to the manner in which fluids act, ſhould be ſupported with greater force, and of conſequence be able to carry the greater ſail. Hence it is plain, that, by raiſing the breadths, we keep them as a reſerve, to be uſed when the ſhip ſtands moſt in need of relief; that is, when ſhe lays moſt over. It may be remarked, that the flat floored ſhips have leaſt need of raiſing the breadths; for, carrying all the weight of their cargo ſo low, they are thereby capable of carrying a great deal of ſail. Though we cannot abſolutely condemn the practice of making

making a ſhip draw more water abaft than afore, yet we cannot approve of any of the rules that the builders have given us to determine the exact difference. A ſhip may be built to a preciſe draught of water, by which the conſtruction will be founded on true principles; but when a ſhip is not built to one preciſe draught more than another, which is the caſe of moſt of the ſhips that have hitherto been built, it will be very difficult, and one of the moſt complex queſtions in naval architecture to determine this preciſe point: One would imagine there is no more to be done but to make the ſhip ſwim in the water, ſo as to be capable of carrying the greateſt ſail; but when a ſhip is very deep in the water, this will greatly increaſe the reſiſtance, and of conſequence be very prejudicial to her ſailing. We need not abſolutely find that part which will meet with leaſt reſiſtance: When a ſhip has but little hold in the water, ſhe can carry but little ſail, and therefore cannot go ſo faſt through the water. The reſiſtance then muſt be calculated, not abſolutely, but relatively, in proportion to the canvaſs ſhe ſpreads. This will be a moſt laborious and tedious calculation, as not only the various and irregular curves which compoſe the body muſt be nicely examined, to aſcertain the reſiſtance in different draughts of water, but likewiſe the weights of every part in the ſhip, and in what manner they are ſtowed; all theſe muſt be given before we can determine, in every caſe, the power that will be ſufficient to ſuſtain the force of the wind; on which account, it will be proper to adviſe the mariners to make frequent experiments of the ſhip's ſeat in the water; for the ſolution of this problem is only an approximation, even when the minuteſt circumſtances are conſidered. It is true, ſome builders, who would not be ſtopt by any difficulties, even ſuch as puzzle the greateſt mathematicians, have imagined they could find out this by another method. Many of them pretend to examine the difference of the draught of water when the ſhip is launched, and would have it to be the ſame when the ſhip is loaded; our readers cannot but pity us, to be obliged ſeriouſly to confute theſe and ſuch parallel maxims. If a ſhip ſails beſt when loaded to the propoſed load-water line, ſhe cannot ſail ſo faſt when ſhe draws only one half, or one third part of it: So there can be no manner of proportion between a ſhip's draught of water, when launched and when loaded: And this method propoſed ſo myſteriouſly to us by the *gens du metier*, and received with too much reſpect by many mariners, ſerves only to confirm us in our opinion, that very little regard ſhould be had to all their other rules.

But if theſe common maxims are found ſo imperfect, it muſt be owing chiefly to the figure they give their ſhips; for it is impoſſible to

 diſcover

difcover, by practice alone, and by experiments, though never fo often repeated, all the properties of an entire furface, which is an affemblage of an infinite number of curve lines and points. There can then be no manner of doubt but it is in this very article the art ftands moft in need of amendment. In general, the fore part is too full, and on that account the ribbands that form it are too round. The mariners are very fenfible that part fhould not be too fharp, but they have not adverted that it will be fufficient for that purpofe to carry the midfhip frame further forward. It may be, that, confidering all thefe particulars, we cannot always rigoroufly follow the precepts of theory, but it will at leaft be of great advantage to know them, that we may have the point of perfection always in view, even when we cannot arrive at it, but are obliged to ftop fhort of it.

If the floor ribbands were formed only by narrowing the breadths of the frames, without any rifing, and terminating the fore part at the extremity of the keel, this would occafion the ribbands to be perfect ftrait lines; by this means, the foremoft frame would be a rectangle, and the bow formed by two vertical planes interfecting one another in a vertical ridge at the extremity of the fore part, where they would form an acute angle. *Fig.* 1, reprefents fuch a bow, wherein the ribbands C A, F D, cannot fail of being ftrait lines.

But if we give a rifing to the frames, and cut off the bow by the fore part of the keel, as in *Fig.* 2, the ridge A D, or common fection of the two vertical planes, would run fo far below it, as is D F, the whole quantity of the rifing, and fo the bow could not be formed by plain furfaces; the ribbands would become curves, and the more fo, by raifing the point D, or augmenting the rifing D F: At the fame time that the figure would be more advantageous, it would approach the nearer to a *maximum maximorum*, in which refides the higheft point of perfection. In fuch a cafe, the fore part would be the figure of a regular demi-conoid; its bafe, inftead of being circular, would be a rectangle.

But what is principally worthy of our notice, is, that, according to the common dimenfions of fhips, it always happens, that when the rifing is the greateft poffible, and that all the vertical ridges at the extremity are vanifhed, and the fore part has by that means acquired the moft advantageous figure of any, the ribbands alfo, having acquired their greateft curvings, will round no more than the arch of a circle of 18 or 20 degrees; or, which is the fame thing, they differ fo little from a ftrait line, that the round in the middle is but the twentieth, or the two and twentieth part of the whole length. Now, taking all this for granted; the builders,

builders, after all their trials, are very far from having found out the true figure of the bow, which they have been obliged to make almoſt ſtrait; ſo far they are from knowing that rule, which would be ſo very uſeful to them, and which they may regard as the ſecret of their art; namely, that the leſs the riſing F D (*Fig.* 2.) is, or the lower they carry it on the frames afore, ſo much the ſtraiter will they make all the ribbands C A, E D, &c.

What we have advanced here depends on a very complicated theory; one may be very eaſily deceived, ſeeing the two points which limit the curve are ſo very near one another, that they will make the ribbands quite ſtrait, as in *Fig.* 1, or give them ſcarce the round of an arch of a circle of 18 or 20 degrees, as in *Fig.* 2; they will acquire this laſt by increaſing the height of the riſing line afore; whereas, by diminiſhing the riſing, the ribbands will come nearly ſtrait. We may, by a diligent attention to this ſingle maxim, without adhering ſtrictly to ſpeculative rules, reap the fruit of the whole; we may keep the form of the midſhip frame, but we ſhall gain much by making the extreme breadth no more than the fifth or ſixth part of the length, if at the ſame time we diminiſh the depth proportionally. This we ſhall clearly demonſtrate, in another place, and likewiſe this moſt ſurpriſing circumſtance, that by diminiſhing theſe two dimenſions, or by increaſing the length, a ſhip may be made to go ſome times as faſt as the wind.

Let us now again return to the ribbands, which may be equally ſpaced on the ſtem, and likewiſe on the midſhip frame, from the head of the floor: It will ſuffice to make them round no more than the twenty-fifth or thirtieth part of their whole length, whether we make them arches of circles, or ellipſes, and then there is nothing to hinder them from being formed in the ſame manner they uſe to make a fair curve.

By this means it will be eaſy to give the bow nearly what figure we pleaſe. After having formed the midſhip frame A D 2 A, *Fig.* 3, and projected the ribbands A W, G Z, &c. take the length of one of theſe, for inſtance, if W A, the breadth ribband, make the ſtrait line W A (*Fig.* 4.) equal thereto, and at the end of it W, draw the perpendicular W v, which may be made equal to W A, as the point v may be aſſumed at pleaſure, and draw the line v A, on the middle of which erect the perpendicular B C, which muſt be the 25th or 30th part of the line v A, when that happens to be the length of the ribband, but when it is ſhorter, as in this caſe, where it is only the projection of it, B C muſt be the 10th or 12th part of it. Then deſcribe an arch of a circle thro' the three points A, C, v; and dividing the line W v into as many equal parts as there-

there are to be frames before the midſhip; draw lines thro' the ſeveral diviſions D, E, G, &c. parallel to W A, to interſect the arch *v* A. Theſe transferred to the line W A, will ſpace the frames properly upon the ribband projected in *Fig*. 3, and will become an arch of an ellipſis, which will have but a very ſmall curving; after the ſame manner the other ribbands may be divided; it muſt only be obſerved that by reaſon of the rake of the ſtem the breadth ribband will be longer than the reſt; their lengths muſt not be repreſented by the line W *v* but by a ſhorter R Q. In order to aſcertain this length, ſuppoſe of the firſt intermediate ribband of which S F is the projection, in *Fig*. 3; if it happens that R A is equal to S F it is only transferring the lines R 1, R 2, R 3, &c. to the projection of the ribband, which will give the proper ſpacings of the frames, but in general produce the line *v* W, and from any point K, taken at pleaſure, draw ſtrait lines to the points 1, 2, 3, &c. theſe lines will divide the line S F proportionally to R A; and by this method we may form as many frames as we pleaſe. Inſtead of erecting the perpendicular on the middle of the line *v* A, *Fig*. 4, we may have it at the third part of it, making A B double of B *v*; the curve A C *v* muſt then be formed by two arches of different circles whoſe centers muſt be in the line C B produced, by uſing the ſame proceſs; in all other circumſtances we ſhall imitate that curve which is propereſt for dividing a fluid.

The after part may be formed by much the ſame method; the ribbands ſhould be almoſt ſtrait, not rounding in the middle above the 25th or 30th part of their whole length; thus the whole ſhip will be nearly the form of two demi-cones, as in *Fig*. 5, whoſe baſes unite at the midſhip frame, which ſeparates the fore from the after part, and ſhould be placed as was before obſerved, at $\frac{5}{11}$ of the whole length from the point B, the extremity of the fore part, whereas the general practice is to preſerve the whole body, or a conſiderable ſpace, nearly of the ſame bulk, and at the ſame time it will be as faſtened to the keel. Although the part A F G, which extends at ſuch a diſtance beyond the keel, may appear to be uſeleſs, yet it cannot be wholly retrenched, becauſe of neceſſity the rudder muſt be faſtened to the ſtern poſt G A. As to the part B C F, it might in a great meaſure be taken away, if it could be done without prejudice to the faſtening of the members together, which is ſo requiſite in forming the body, and were there not another very important reaſon for not retrenching it, and that is becauſe this will conduce very much to her keeping a good wind, when plying to windward: It is true it will be a great diſadvantage to her in wearing, and make her very ſubject to broach

too,

too, but to remedy this we need only give her the more head ſail, ſo that we may without any inconveniency unite all theſe advantages.

It muſt be remarked, that when ſuch a ſhip is formed ſo as to ſail on an even keel, we ſhall gain nothing by making her draw more water abaft than afore, the reſiſtance which the fore part meets with in dividing the fluid is leſſened very little, or ſcarce perceptible; on the other hand, the rudder cannot fail of producing its effect, becauſe the water will eaſily ſtrike it with its whole force. When a ſhip goes on an even keel, there is nothing to hinder us from laying the decks parallel to the keel, it is likewiſe plain there will be no occaſion for laying the wing tranſom ſo high, it will be ſufficient to make it higher than the depth of the hold, about the eight or ninth part of that depth.

All that we have ſaid belongs chiefly to frigates, that are built on purpoſe for ſailing, without regarding their capacity for carrying heavy goods. But when this is required or when it is neceſſary to have ſeveral decks, and to carry guns, &c. we then form the bow according to *Fig.* 6. At the ſame time we make the whole immerged part fuller, which will contribute much to prevent her pitching. *Fig.* 6 is only a ſketch to repreſent things in general; the builders no doubt can reconcile all the angles, and breaches, or ridges of this figure: If we give the bow as much riſing as poſſible, all the curves which end at the extremity A, will then become arches of circles, of 18 or 20 degrees; but in diminiſhing the riſing, and making the ribband E D horizontal, that will become quite ſtrait; the other ribbands as C M will likewiſe become ſtrait and parallel to the firſt, for the whole ſpace intercepted betwixt the planes B F E C, and N D M. But the rake of the ſtem, together with the inclination of the ſides of the foremoſt frame B F E C, will occaſion the upper ribbands to be curves; the ſurface D M C E will be a plane, if the ſide E C of the midſhip frame be a ſtrait line; whereas becauſe E C is commonly a curve it will become cylindric, and in every caſe D M will be perfectly equal to E C. When the flat E F of the midſhip frame is half the extreme breadth, the half breadth L M, which is equal to H C, will be half of G C; ſo the breadth N M of the bow, above D, at the extremity of the keel, will be equal to B C, half the extreme breadth. It will be needleſs to inſiſt on the manner of deſcribing the frames; it is plain that each of them, as P R S T, will be formed by two parts perfectly equal to thoſe B F K, and H E C of the firſt, but they approach to one another. The diſtance R S, at which they muſt be placed, will be the flat of each floor or frame, and that flat will diminiſh in proportion to the diſtance from D, the extremity of the keel. In regard to the part A N M D, it may be

formed

formed by producing each ribband, as C M, by an arch of a circle A M C M, a ſtrait part of the ribband being a tangent to it in the point M; this will occaſion the whole ribband C M A to be rounder, which will be more ſo if we make the flat F E of the midſhip frame leſs, ſince H C becomes greater, and L M is equal to H C. This bow, whether we imitate it only in the principal particulars, or conform to the whole, will meet with greater reſiſtance in paſſing thro' the water than that ſhewn before: But the great breadths which are carried high, from B I C, the firſt ſection, to the height above the exremity of the keel, will at leaſt make them more capable of ſuſtaining the weight of the ſails. This form will make the ſhip more capable of reſiſting the violent pitchings, occaſioned by the ſeas ſtriking one end of the ſhip, which lifts it up, the other end at the ſame time being plunged into the water, continues to ſink till it is ſtopped by the reſiſtance of the water, or by the weight of that column of water it diſplaces. Sometimes the ſhip is not ſhocked; it is only the ſea that looſes its horizontal poſition by the agitation of the ſurf or waves; the ſea all of a ſudden withdraws itſelf from the bow, or from the buttock, which of neceſſity will occaſion that part of the ſhip to fall down till it find a ſupport: Theſe violent motions may occaſion the carrying away of the maſts, and will always be prejudicial to her ſailing. It is plain there can be no way of preventing, or even diminiſhing theſe accidents, but by making them fuller both afore and abaft; we muſt have recourſe to experience to form the ſhip ſuitable to the particular ſervice ſhe is deſigned for; but it is always to be remembered, and it is demonſtrable, that when we have only velocity in view, and are to ſail in ſmooth water, as in the *Mediteranean*, with fine weather, the form of the ſhip ſhould differ very little from two cones joined together by their baſes. In ſhort, if the ſhip is not full enough for the purpoſe, we may continue the whole breadth for a conſiderable ſpace; the fifth, fourth, or at moſt the third part of the whole length, and then form the fore part by the preceding rules. It ſeems to me, that when we have got a ſufficient capacity in the hold, we ſhould raiſe the floor ribbands afore; otherwiſe, the bow would too much obſtruct her ſailing. This laſt property is chiefly to be obſerved in ſhips of war, where the breadth is continued ſtrait but a ſmall ſpace. If, inſtead of ſuch a veſſel as is commonly built for a tranſport ſhip, we ſhould build a fly-boat; we need only take for a model the figure of a rectangled parallelopiped, and form the fore and aft part by two inclined planes, giving the ſtem and poſt a rake. We muſt be always careful to preſerve the two parts repreſented by B C F, and F G A, *Fig.* 5.

As

As to the rake, if the whole length of the ſhip be 144, the rake of the ſtem may be about 44, and when the breadth is continued for a good ſpace it may be 32, and 68 for the rake of the ſtern poſt. That form of a fly-boat, where we need only round off the corners, will be the moſt perfect of any; and, beſides, as a great part of the ſide is ſtrait, it will be thereby proper for carrying guns, and fit for a ſhip of war.

In the twelfth chapter, which concludes the firſt ſection, he ſhews the manner of launching a ſhip.

In the ſecond ſection, our author treats of the furniture of a ſhip; ſuch as the rudder, capſtan, and pumps, which takes up the firſt two chapters. The third chapter is on the cables and anchors.

The cables and anchors, ſays he, are of indiſpenſible uſe to hold a ſhip when in a road-ſtead, where ſhe is often expoſed to all the fury of the wind and the ſea. Every ſhip has at leaſt five or ſix cables of different dimenſions; and to regulate the largeſt, which is called the maſter cable; they make its circumference the 24th part of the extreme breadth; or, which is the ſame thing, one inch to every foot of the half breadth. Suppoſe a ſhip to be 48 feet extreme breadth, the maſter cable ſhould be 24 inches circumference; but if the ſhip be 20 feet broad, the cable will be 10 inches; and the dimenſions of the other cables will be leſs, and is always eſtimated by their circumferences. In *France*, the length of all cables, whether great or ſmall, is 600 feet, or 120 fathoms; for a fathom is always accounted five feet.

It is neceſſary to have the cables longer, on which account, they are obliged to ſplice ſeveral to one anothers ends; but it will be very difficult to make them longer in one piece; the firſt threads that form them are of double the length, and more: Thoſe of a cable of 120 fathoms long are 180, ſo that they looſe a third part of their length in twiſting them in the manner they do, to make the cable. Theſe threads muſt be in length and proportion to the propoſed length of the cable, the execution of which will be attended with difficulty.

One thing may be remarked, which may ſerve in all the different ſorts; that the weight of one fathom of cordage, in pounds, is nearly the fifth part of the ſquare of its circumference. This rule will always be pretty exact, eſpecially, when there is not too much tar put in the yarns; as for inſtance, the weight of a fathom of cable of 24 inches, will be found, by multiplying 24 by 24, and dividing the product by 5, to be $115\frac{1}{5}$ pounds, and the whole cable, which is 120 fathoms long, will weigh 13824 pounds. The weight of one fathom of a cable of 10 inches will, by this rule, be 20 pounds; for 20 is the fifth part of 100, the ſquare of 10; and the weight of the whole cable of conſequence will be 2400. The weight of a whole cable may be had at one operation, by multiplying the ſquare of the circumference by 24.

The cables would be uſeleſs without the anchors, the form of them is to be ſeen in *Fig.* 7, which is the propereſt figure for catching hold, in the ſand, or in the mud, in the bottom of the ſea. The anchors in *France*, *England*, and *Holland*, are of forged iron; but in *Spain* they may be ſeen of copper, and likewiſe, in ſeveral parts of the *South Sea*.

The part A D, is called the ſhank, at the extremity of which there is a ring E; A B and B C, are the two arms, K C and I B, the fleucks; the ſtock F G, which is of wood, is fixed at the end of the ſhank, at right angles to the fleucks; the uſe of this is to make the anchor fall, ſo that one of the fleucks will infallibly catch the ground. The two arms generally form the arch of a circle, of which the point H, is the center, being three eighths of the ſhank from the point A; and each arm is equal to three eighths of the ſhank, or to the radius; ſo that the two arms together make an arch of 120 degrees: The fleucks are half the length of the arms, and their breadths two fifths of the length of the arms. In regard to the thickneſs they generally make the circumference at the throat A of the ſhank, about the fifth part of its length, and the ſmall end two thirds of the throat; the ſmall end of the arms of the fleucks, three fourths of the circumference of the ſhank at the throat. Theſe dimenſions ſhould be bigger, when the iron is of a bad quality, eſpecially when we uſe caſt, inſtead of forged iron.

When theſe dimenſions are obſerved, an anchor of 16 feet 9 inches long, will weigh about 7000 pounds; for the workman making ſome of theſe parts not exactly to the dimenſions, will cauſe a conſiderable difference in the weight: But if all anchors were ſimilar, which they ſhould be, their weights would be in proportion to the cubes of their ſhanks. There is a ready way to find the weight of any anchor, which is to take the length of the ſhank in inches, and divide the cube of that by 1160. Suppoſe the ſhank 10 feet long, or 120 inches; we are only to divide 1728000, the cube of 120 by 1160, the quotient 1545 will be the weight of that anchor in pounds: But if the weight were given, and the length required, we muſt multiply the weight by 1160, and the cube root of the product will be the required length in inches.

As our author has given us no reaſon, why we muſt take 1160 for a conſtant diviſor, or multiplier; I ſhall here endeavour to demonſtrate it: But, firſt obſerve, that if the length of the ſhank of any anchor be given, and its weight, we may then find the weight of any other anchor, whoſe

whose length is given; and, consequently, if the weight be given, we may, by the reverse, find the length, since all similar solids are in proportion to the cubes of the similar sides. Now M. *Bouguer* has given us this; for he tells us an anchor of 16 feet 9 inches, that is, 201 inches, weighs 7000 pounds. Hence, we have the following general rule: Let $a = 201$ inches, the given length; $e = 7000$ the given weight, $l =$ any other length; $w =$ the required weight, then $a^3 : e :: l^3 : \frac{l^3 e}{a^3}$, we shall illustrate this by the logarithms. The question he proposes; is, admit the length of the shank 10 feet, what is the weight of the anchor?

The first thing is to find the logarithms of the lengths, and, multiplying that by 3, we have the logarithms of the cubes of the lengths.

$a = 201$	2.303196×3 is 6.909588
$l = 120$	2.079181×3 is 6.237543

Having thus found the logarithms of the lengths, we have the solution by the rule of three, by the logarithms.

As 201^3	6.909588
Is to 7000	3.845098
So is 120^3	6.237543
	10.082641
To 1489	3.173053

Now as the logarithms of the first and second terms are constant numbers, instead of adding the first and second terms, and, from the sum, subtracting the first; we may subtract the difference of the first and second terms, which will likewise be a constant number, and the result will be the same, as by the following operation.

The first term	6.909588	the third term	6.237543
the second	3.845098	difference	3.064490
difference	3.064490	the fourth term	3.173053

The reason of this is very plain, for the sum of the second and third terms is .082641, now out of this we are to subtract the first term 6.909588; which may be done, by first subtracting 3.845098; and again, subtract from that remainder, 3.064490: Since these two numbers make 6.909588 the first term, which is the whole number to be subtracted; and if we do not add the second term to the third, we have only the third term left, which is 6.237543; and if from this, we subtract the constant difference 3.064490, we in effect subtract 6,909588, from

10.082641, so the result must be the same, as by the common rule, and this accounts for making 1160 a constant number: For 3.064490, is the logarithm of 1160; which, by an error in the press, is in the original 3.0644580.

We may by the same principles, make a general rule for finding the weight of any shot, whose diameter is given; but we must first find the weight of one shot by a pair of scales. A shot of four inches diameter, is supposed to weigh nine pounds; therefore, as the cube of 4 is to 9, so is the cube of the diameter of any other shot to its weight.

The cube of 4 is 64; its logarithm is 1.806180; the logarithm of 9 is 0.954242; their difference is 0.851938. Hence, we have the following general rule. From the logarithm of the cube of the diameter, subtract the constant logarithm 0.851938, the remainder will be the logarithm of the weight.

Example. Let the diameter be 8 inches; required the weight?

8	0.903090
	3
cube	2.709270
constant log.	0.851938
required weight 72	1.857332

This rule may be applied to gauging of similar vessels, or finding the weight of similar solids, which will always be in proportion to the cubes of their diameters, or lengths, or any other similar dimensions.

But if the solids be of equal lengths, and differ only in their bases, as is the case of cables; their weights will be in proportion to the areas of their bases, or, which is the same thing, to the squares of their circumferences; as, for instance, if a ten inch cable weigh 20 hundred weight; what will a cable of 5 inches weigh?

As 100 the square of 10	2.
Is to 25 the square of 5	1.397940
So is 20 hund. wt.	1.301030
To 5 hund. wt. the required wt.	0.698970

It is upon this principle the rope table is constructed, which is on some pocket rules.

To return to our author: These operations, says he, may be done with greater ease by the logarithms, only taking three times, the logarithm of the length of the shank in inches, and from thence, subtracting the constant logarithm of 1160, which is 3.0644580, the remainder will

will be the logarithm of the weight of the anchor in pounds; but if, on the other hand, the weight be given in pounds, we need only add the logarithm of the weight to the conſtant number 3.0644580; and, dividing this ſum by 3, we ſhall have the logarithm of the required length.

The ſmalleſt ſhips have five or ſix anchors, and the greateſt generally eight. The mariners have different rules for determining the weight of the anchors; and, on account of the conveniency of working the ſhip, they have eſtabliſhed it as a rule, that the biggeſt anchor, or, in their terms, the maſter anchor, ſhould be three eighths of the beam.

Another rule, but which does not agree with the firſt, as we ſhall preſently ſhew, is to make it weigh half rhe cable; ſo a firſt rate, which is 48 feet broad, and whoſe cable is 24 inches circumference, weighs 13824; her maſter anchor ſhould weigh 6912 pounds, and the other anchors ſhould be half the weight of their reſpective cables. The ſmalleſt anchor is the cadge, or ſtream-anchor; in ſhips of the firſt claſs it ſhould weigh 2300 pounds, and the length be about 11 feet 7 inches. When the length of the anchors is three eighths of the beam, as in large ſhips, the weight of the anchor will be in proportion to the ſolidity of the ſhips, ſuppoſing them to be ſimilar; and, if the ſhip be twice as broad, the anchor will be eight times more weight; but, according to the ſecond rule, the weight of the anchor ſhould be half the weight of the cable, and the weight of the cable is in proportion to the ſquare of the breadth; ſince it is only the circumference of the cables that differ in great and ſmall ſhips, the length being always 120 fathoms in all ſhips. When the ſhip is double the breadth, the weight of the cable will then be four times more; and of conſequence the weight of the anchor, which is in proportion to that of the cable, will be half the weight it would be by the firſt rule; that is, in proportion to the beam.

Although the ſecond rule makes the anchors a great deal lighter, yet we may conform to it, becauſe that will be ſufficient when it falls in good ground; but when the ground is ſoft and ouzie, the mariners make uſe of ſeveral expedients to ſuccour the anchor; but the beſt of all is, and which is chiefly practiſed, to ſplice ſeveral cables at one another's end; ſo they will rub on the ground, on account of their weight; and by this means, the effort of the ſhip, on the anchor, will be diminiſhed.

A ſhip ſeldom anchors in above 40 fathoms depth, and then it will be very proper to have two cables at one another's ends; for, if there is but one, the lower part of it will ſcarce bear on the ground, and the anchor will be obliged to ſuſtain all the ſhocks and jerks of the ſhip, which will come quite home to the anchor; it will not pull it quite out of the ground,

ground, but drag it, in the ſea term; ſo the ſhip will drive, and be in danger of being loſt on the firſt rocks. *Fig.* 8, makes this very plain; A D is the anchor, at the bottom of the ſea; D M N is the cable, by which the ſhip rides, of which we have here only repreſented the bow; N the hauſe-hole, thro' which the cable paſſes, between the two lower decks; The rope A B, faſtened to the croſs, or throat of the ſhank, is called the buoy-rope, which ſometimes ſerves to weigh the anchor; this, in the ſea term, is called, weighing it by the hour; 5 is the buoy, which ſerves to know where the anchor lies. It is very plain, that, if the length of the cable be doubled, or trippled, the anchor will be dragged horizontally, and with a great deal leſs force; for its effort will be diminiſhed by the whole power of the friction of the part D M on the ground.

A ſecond advantage is, that by having ſeveral cables at one another's ends, they will be leſs liable to breaking; for all the parts, lying more upon a level, they will oppoſe the ſhocks of the ſea in a more perpendicular direction to the motions which the ſhip receives; whereas, when the cable is not ſo long, it will be nearly vertical to the anchor, and therefore cannot bear ſuch a ſtrain: Let the ſpace L O repreſent the force with which the ſhip endeavours to recoil; and having compleated the rectangle L O P Q, L P, the part of the cable which is the diagonal, repreſents the effort which the cable ſhould ſuſtain, which is greater than O L; and the more it approaches to be vertical, the more it is augmented, though O L continues the ſame.

It is plain, then, that a ſhorter cable is charged with a greater effort, and ſhould therefore be ſtronger, otherwiſe it will only bear the ſame ſtrain in the proper direction, and will not be ſufficient, in an horizontal direction, which is that in which the ſhip endeavours to drive: It is true, the horizontal effort O L is all that is to be reſiſted; but then the cable, being inclined, cannot reſiſt this, without being furniſhed with a force ſufficient to ſuſtain the whole effort P L.

The long cable will not be ſo apt to break as the ſhort one, becauſe it will bear a great deal more ſtretching, before it comes to the greateſt ſtrain; ſo that, at the firſt violent tugg, becauſe it will not bear ſtretching, it muſt infallibly break.

A long cable may be compared to a ſort of ſpring, which may be very eaſily extended; and recovers its firſt ſituation, as ſoon as the force that extended it is removed. Beſides all this, a ſhip will ride much ſmoother with a long cable than with a ſhort one, and be leſs apt to plunge in the water; whereas, as the mariners have too often experienced, when

when a ſhip rides with a ſhort cable, ſhe frequently pitches all the fore part under water.

The fourth chapter is on the power and action of oars; and, in the fifth chapter, he gives the following proportions for maſts and yards.

All ſhips have generally four ſtanding maſts; the firſt is the main-maſt, which ſtands in the middle of the ſhip: The ſecond is the fore-maſt, which is pretty near the fore end of the keel; this is nearly as long as the main-maſt: The third is the bowſprit, which, inſtead of ſtanding upright, ſtives forward, and reſts on the head of the ſtem: The fourth is the mizen-maſt; but ſome ſmall ſhips have not this maſt; it ſtands abaſt, towards the poop. Beſides theſe, the main and fore maſts have top and top-gallant maſts, and the mizen-maſt a topmaſt. All theſe maſts have their particular ſails, and are named according to their reſpective maſts.

The main-maſt is placed in the middle of the ſhip, meaſured from the head of the ſtem to that of the poſt, or its whole diameter abaſt the middle of the ſhip: All the builders agree in this, but they differ widely as to the reſt; ſome place the fore-maſt preciſely at the fore end of the keel; others again take the 40th or 50th part of the whole length, from the ſtern, for its place; and ſome will have it ſtand on the ſtem. The bowſprit generally ſtives, ſo as to make an angle of 35 degrees with an horizontal line. Laſtly, the mizen-maſt is about three ſixteenths of the length of the whole ſhip, before the head of the ſtern poſt: If the ſhip be 160 feet long, the mizen-maſt is 30 feet before the ſtern poſt.

In *France*, the main-maſt is generally, in length, twice the breadth and half the breadth of the ſhip; whereas, the *Engliſh* make it only twice the breadth and two fifth parts of the breadth; ſo, ſuppoſing the ſhip to be 40 feet broad, the *French* builders would make the main-maſt 100 feet long, whereas the *Engliſh* make it only 96.

The *Dutch* make their maſts ſomewhat longer than ours, though they agree with all other nations in regulating the lengths of their maſts by the breadth of the ſhip. The head of the maſt is always the tenth part of the length of the maſt.

The diameter of the main-maſt, at the partners, is as many inches as three fourths of the extreme breadth is feet; ſo, if the extreme breadth be 40 feet, the main-maſt will be 100, and the diameter, at the partners, 30 feet, that being three fourths of 40; or, which is the ſame thing, the 40th part of the whole length of a ſhip ſuppoſed to be 160 feet: The diameter at the head is generally allowed to be two thirds of that at the partners, which will make it 20 inches.

I muſt own, ſays our author, it is with violence to myſelf that I am am obliged to give a detail of all these rules, which have not the least foundation in reason, and are proper only to be confuted.

The fore-mast is in length twice the breadth and one quarter more; and its diameter, as well as that of the other lower masts, is about the 39th part of the whole length; others make it nine tenths of the length of the main-mast.

The length of the bowsprit, is the breadth and half breadth of the ship, and its diameter the twenty-seventh part of its length; so if a ship be 40 feet broad, the bowsprit will be 60 feet long, and $26\frac{2}{7}$ inches diameter at the bed, and at the cape it will be half what it is at the bed.

Lastly, the mizen-mast is, in length, the breadth and three quarters of the breadth of the ship; and its diameter, at the partners, as many inches as seven sixteenth parts of the main breadth is feet, or rather, the forty-eighth part of its length.

Proportions for Top-masts.

The maintop-mast, in length, is the breadth and half breadth of the ship, which makes it equal to the bowsprit; the diameter at the cape is about the forty-third part of its length.

The foretop-mast, in length, the breadth and three eights of the breadth; the diameter, at the cape, the forty-third part of the length.

The mizen-top-mast is half the length of the main-top-mast; and its diameter, at the cape, half the diameter of the main-top-mast.

The main topgallant-mast is five twelfths of the length of the main-top-mast; and it is half the diameter.

The fore top-gallant-mast is four sevenths of the length of the fore-top-mast.

The spritsail topmast is, in length, two fifths of the main breadth; and its diameter generally as many inches as there are feet in seven thirty-six parts of the breadth; that is, somewhat less than the twenty-fifth part of the whole length.

Proportions for Yards.

The main-yard, in length, is twice and one sixth part of the main breadth; the diameter, at the slings, one inch to every foot in two thirds of the main breadth; or, which is the same thing, the thirty-ninth part of the whole length: The yards are of a quite different figure from the masts; they taper from the slings towards the yard-arms; the diameter, at the end, is one third of that at the slings.

The main-top-sail yard, in length, is the main breadth and quarter of the breadth; the diameter, at the slings, half that of the main yard.

The

The main-top-gallant yard, in length, is three quarters of the main breadth; and the diameter, at the flings, half of that of the main top-fail yard.

The fore yard, in length, is exactly twice the main breadth of the ſhip; its diameter, at the flings, one inch to every foot in five eights of the breadth.

The fore-top-ſail yard is, in length, the breadth and ſixth part; and its diameter ſeven fifteenths of that of the fore yard.

The fore-top-gallant yard is, in length, two thirds of the breadth; and its diameter half that of the fore-top-ſail yard.

The ſprit-ſail yard, in length, is the breadth and one quarter; and its diameter, at the ſlings, one inch for every foot in the third part of the breadth, which will be half the diameter of the main yard.

The ſprit-ſail top-ſail yard, in length, is three quarters of the breadth; and its diameter ſeven ſixteenth parts of that of the ſprit-ſail yard.

The mizen yard is inclined, on account of the triangular form of the ſail, and is the hypothenuſe of a right angled triangle; it is, in length, twice the breadth of the ſhip, and its diameter one inch to every foot, in one third of the breadth; at the lower arm it is two thirds, and at the upper arm one third of the ſlings.

The mizen top-maſt is, in length, three fourths of the breadth; and its diameter, half that of the mizen yard.

Of the proper Figure of Maſts and Yards.

Our readers, ſays our author, know very well that the maſts, as well as the yards, are round, like cylinders, or cones; but, perhaps, they imagine the ſides are ſtrait.

The beſt maſt-makers make the ſides of their maſts curves, which form an arch of an ellipſe. Our author here ſhews us how they form theſe curves; for which we refer to *Chap.* VII. *Sect.* I. *pag.* 106. of the foregoing Treatiſe; and proceed to the 6th chapter, where he makes ſome remarks and experiments on the before-mentioned proportions.

It is eaſy to judge, that the dimenſions of the ſails are regulated by that of the maſts and yards.

The main-maſt, of itſelf, is 120 feet; the main-top-maſt 72, and the main-top-gallant maſt 30 feet, a monſtrous height, when all theſe are on end; and they are proportionally ſo in leſſer ſhips: If the mariners would but attend to what they ſee every day before their eyes, they would eaſily be convinced, that it would be a great advantage to ſhorten them prodigiouſly; and, if they pleaſe, make the yards longer, to gain what they lose in the height of the masts. A small sail, when very high, will have more power to make a ship heel than to go a-head; because, being placed at the end of a long lever, it is removed at a great distance from the center of gravity; and whereas a larger sail, when placed low, has less power to heel the ship; yet it does not hinder it from exerting all its effort in respect of sailing. All that the mariners have to plead for this rule is, that experience, and the universal consent of all nations, are on their side; but we can assure them, experience, instead of favouring them, makes quite against them. There are daily instances of ships being dismasted at sea; and when they have got up jury-masts, have sailed as fast as with the proper masts; on the contrary, when they give a ship taunter-masts, she will not sail so fast as before; an instance of this happened some years ago in his majesty's ship the *Content*, which they masted beyond the common rules; or, perhaps, only observed them to the utmost rigour, and immediately she lost a great part of these advantages; a certain mark that the masts are too high.

We perfectly agree, with our author, that when ships are dismasted in a very hard gale of wind, and the sea running very high, they will sail better with jury than with their proper masts, even when the top-gallant masts are struck, and all their sails handed; but when the storm abates, and becomes moderate, so that a ship can carry top-gallant sails, it is presumed she would soon run another ship, with jury masts, out of sight.

But the height of the masts, says our author, is not the only fault that attends these rules; there is another secret evil which they carry in their bosom; they do not conform to the laws that should be observed in ships of different dimensions. If one ship is twice as long, and twice as broad, they make the sails of this last double the dimensions of the first; but, as all ships are allowed to heel, a small ship should have a great deal less sail, in proportion, than a great ship: Supposing one ship half the dimensions of another, the small ship will only be the eighth part of the solidity, and the eighth part of the weight of the great one; and, as it is the weight that opposes the wind, when it makes its effort to overset, or at least to heel the ship, she will have but the eighth part of the absolute force which is necessary to sustain the sail; but this same force, which is diminished to one eighth part, is collected in the center of gravity, and applied with double disadvantage. Seeing all the dimensions are less by one half, the center of gravity will be but half the distance below the decks, or load-water line; so the relative force, by which the weight of the ship opposes the effort of the wind, is only the sixteenth part of what the large ship has. In order to judge if these rules be good or bad, we have only

only to examine if the relative force, which the wind has to overſet a ſmall ſhip, be likewiſe diminiſhed to a ſixteenth part; and, if they agree, the equilibrium will not be deſtroyed. This will be a mark that the rules are perfect, and we may continue to make the maſts proportionate to the other dimenſions of ſhips.

But when the dimenſions of the ſails of ſmaller ſhips are half the dimenſions of the large, the ſurface of the ſails is only diminiſhed one quarter: It is true, the center of that effort is but half the height above the ſhip, and, of conſequence, applied to the lever of only half the length: But, when all is conſidered, the relative force which tends to overſet, is only diminiſhed to one eighth part; whereas the other is diminiſhed a ſixteenth part, as we have juſt now proved. It is plain then, that the force of the wind will predominate, being two-fold too great; ſo that if the great ſhip be properly maſted, the ſmall one cannot be ſo likewiſe, but will be in danger of overſetting.

To ſpeak in more general terms, the relative force with which the ſhip oppoſes the effort of the wind, is diminiſhed in proportion to the ſquare of the ſquare of the keel, or of the breadth and the weight; or the abſolute force is diminiſhed in proportion to the cubes. But the relative effort of the wind is not diminiſhed, but as the cube of the keel, or as the cube of the breadth; ſince the abſolute force of the wind, which is proportioned to the ſurface of the ſails, is diminiſhed but as the ſquare; and that the height of the maſt, which ſerves as a lever to that force, diminiſhes only in proportion to the keel, or to the breadth; ſo, in ſmall ſhips, the force which they have to ſuſtain the preſſure of the ſails is always diminiſhed, in a greater proportion, than the relative force of the wind to overſet them; and, of conſequence, if there be an equilibrium betwixt theſe two forces in large ſhips, it cannot ſubſiſt in ſmall, the firſt being too little, and the force of the wind too great. It follows then, that the common rules are defective, and will be at leaſt ſubject to one of theſe two inconveniencies; for the ſmall ſhips, being over-maſted, will not be able to carry ſail with ſafety; and, on the contrary, the great ſhips, for want of ſufficient maſts, will loſe the advantages the taunt maſts would procure.

The common rules being thus found defective, we cannot ſubſtitute others ſo ſimple in their room; but, if we had but one ſhip properly maſted, we might, by that, regulate all the maſts of ſimilar, or nearly ſimilar ſhips. The relative force which ſhips have to ſuſtain the preſſure of the ſails, is as the ſquare of the ſquare of their ſimple dimenſions; and the relative force, which the maſts have to overſet, is as the breadth of the ſails multiplied by the ſquare of their height; ſince this height augments the extent of the ſails, and at the ſame time makes the center of their effort higher: On the other hand, we can ſcarce diſpenſe with regulating the breadth of the ſails by that of the ſhip; we may make them more or leſs, but they ſhould always depend on one another. So, ſince the relative force of the ſhip, to ſuſtain the preſſure of the ſails, is as the ſquare of the ſquare of the breadth, the relative force which the ſails have to make her heel is as the product of that ſame breadth, by the ſquare of the height of the maſt: But if there be an equilibrium betwixt theſe two forces, there will be an equality of ratios betwixt the two quantities that expreſs them; and this equality will ſubſiſt if the two quantities divided by the breadth. Hence it follows, that, to have two ſimilar ſhips properly maſted, the ſquares of the heights of their maſts muſt be as the cubes of their breadths, or of their lengths. This theorem may ſerve as a rule; and it will always be eaſy to determine the dimenſions of the maſts of any ſhip, provided we have another properly maſted, which may ſerve as a ſtandard.

It ſeems there can be no inconvenience in regulating all maſts by thoſe of the third claſs. In a ſhip of the third claſs, which is 137 feet long, the ſails on the main-maſt are generally about 118 feet high. In order then to find the height of the ſails of a ſimilar ſhip, which is 83 feet long, we have only to make this ſimple proportion: As the cube of 137 is to the ſquare of 118, ſo is the cube of 83 to the ſquare of the height of the ſails, on the main-maſt of the ſecond ſhip; this ſquare is 3096; and, of conſequence, the required height of the maſt is about $55\frac{3}{5}$ feet; which, by the common rules, would be $71\frac{1}{2}$ feet. Tho' this operation is not long, it may be ſhortened by the logarithms.

But if the ſecond ſhip is not ſimilar to the firſt; if ſhe be either broader or narrower, deeper or ſhallower, the maſts muſt undergo a ſecond change in proportion to the breadth; that is, if the ſhip, which is 83 feet long, inſtead of 23 feet broad, according to the common rules, be only $15\frac{1}{3}$, or two thirds of 23, the height of the maſt muſt be only $37\frac{1}{15}$, inſtead of $55\frac{3}{5}$. It is eaſy to remark, that the ſhip being the ſame length, but a conſiderable change in the breadth and depth, the height of the maſts muſt receive a proportionable change.

For, ſuppoſing that the breadth of the ſails is regulated by that of the ſhip, and that the height of the maſt is likewiſe changed in proportion to the ſame breadth of the ſhip, the extent of the ſails, and, in conſequence, the abſolute impulſion of the wind, will be in proportion to the ſquare of that breadth, and its relative force in proportion to its cube; at the ſame

tim

time that the relative force with which the weight of the ſhip reſiſts the inclination, is proportioned to the ſame cube, and not to the ſquare of the ſquare, ſince the length of the ſhip is ſuppoſed ſtill the ſame; for it follows from thence, that the alterations made in the ſails, anſwer exactly to thoſe made in the breadth of the ſhip, and that the equilibrium is no ways altered. If the breadth be doubled the ſails will be doubled, both in breadth and depth; ſo the ſurface will be quadrupled; and, when the height of the center of gravity is likewiſe doubled, its force will be eight times greater; but if the relative force of the wind, to overſet the ſhip, be eight times greater; on the other hand, the weight of the ſhip which oppoſes that has eight times greater force, and then we ſhall have nothing to fear. The ſhip in effect has the ſame number of vertical ſections perpendicular to the keel, which are the elements of the ſolidity, but each will be quadrupled, and the quadrupled weight of the ſhip, being ſituated twice as low, or with double advantage, ſince the depth is likewiſe doubled, will have eight times the force preciſely, as is neceſſary always to retain an equilibrium with the effort of the wind. We now perceive the propriety of joining this ſecond rule with the former, which every one may eaſily do, who has one ſhip properly maſted, by which to determine the dimenſions of the maſts of all other ſhips, even of thoſe which are not ſimilar, provided the vertical ſections of the immerged part be ſimilar.

The firſt rule is, that the ſquares of the heights ſhould be as the cubes of the ſimple dimenſions.

The ſecond is, that the heights of the maſts ſhould be proportionate to the breadth of the ſhips, provided they be the ſame length.

Theſe two rules being admitted, we may uſe the beſt we can pick out of the common rules, and examine the heights of the maſts of each ſhip, as if ſimilar to thoſe of the third claſs, as they build them at this time; and then we need only enlarge, or diminiſh, the ſails, and the heights of the maſts, already found, according as the ſhip is great, or ſmall.

We may find other rules, which tend to the ſame end with the preceding. As for example, a third is, that in ſhips of the ſame breadth, but of different lengths, the heights of the maſts ſhould be as the ſquare roots of the lengths; for the relative force which theſe ſhips have to ſuſtain the preſſure of the ſails, or to oppoſe the inclination, is proportionate to their lengths; ſeeing the other dimenſions are no ways altered. The center of gravity is neither raiſed, or lowered; it is only the whole weight that is greater or leſs, according to the length; and the relative force will always

always be in the ſame proportion: But when the breadth of the ſhip continues the ſame, that of the ſails will likewiſe be the ſame; and the relative force they have to make the ſhip heel, depends wholly on their height, but that is two ways: The firſt is, becauſe the height of the maſt will increaſe the ſurface of the ſail expoſed to the wind; the ſecond is, becauſe the center of effort is raiſed, or the lever is longer; ſo the relative force of the ſails increaſes the ſquare of their heights, and in caſe of an equilibrium, that ſquare muſt be proportionate to the length of the ſhip, which expreſſes the other relative force: And of conſequence, the heights of the maſts and ſails ſhould be proportionate to the ſquare root of the length. Suppoſing that, without altering the breadth and depth, we ſhould make the ſhip four or nine times longer; we need only, according to that rule, double or triple the heights of the maſts. Laſtly, if we add this third to the ſecond above mentioned; namely, that in ſhips of the ſame length, but of different breadths, the heights of the maſts ſhould be proportionate to the breadth, we may from thence deduce the following fourth theorem.

In ſhips of different lengths and breadths, the heights of the maſts ſhould be in a compound proportion of the breadth and of the ſquare root of the length, or they ſhould be as the products of their breadths, by the ſquare roots of their lengths.

Such of our readers, continues our author, as are not well verſed in geometry, may eaſily be convinced of the truth of the moſt part of what has been ſaid on this head, by trying experiments. If the heights of the maſts ſhould have the ſame proportion in all ſhips, it muſt hold in the ſmalleſt as well as in the largeſt; and, on the contrary, if thoſe rules are erroneous, the true way to diſcover the fault will be, to maſt an enormous large ſhip by theſe rules, and likewiſe a very ſmall one; perhaps one or two feet long; this will be, as the ſaying is, hitting the nail on the head. We may by this way bring the rule to ſuch a proof, as may be deemed the true touch ſtone. When I was at *Havre de Grace*, continues our author, and ruminating on theſe things, I cauſed two ſmall ſhips to be made perfectly equal; and of the ſame form with the *Gazele* frigate, building at that time for the king. My two ſmall ſhips were each about 18 or 20 inches long, I cannot be poſitive to the exact length; but this I may venture to aſſert, that they were exactly ſimilar to the frigate, and one of them maſted according to the eſtabliſhed rules. I took upon me to maſt the other, which I did not to the utmoſt perfection, that I might depart as little as poſſible from the common rules. In ſhort, we gave the two ſhips the ſame loading and ballaſt, we carried them to a piece of water of ſufficient

ſufficient extent for our purpoſe, where they were expoſed to the whole force of the wind, which then blew pretty hard; the experiment was ſcarce begun, when that maſted in all reſpects ſimilar to the *Gazele*, overſet topſy-turvy a hundred times, to the great aſtoniſhment of all the ſpectators: Not conſidering that although all the parts could be made proportionate to thoſe of the frigate, but 50 or 60 times leſs than the correſponding parts of the frigate, yet they could not at all abate the fury or force of the wind, and by this means they expoſed the little ſhip to a perfect ſtorm ſo furious, that the greateſt ſhip could never encounter. It is granted, continues M. *Bouguer*, that the ſails of the ſmall ſhips are 60 times leſs than thoſe of the frigate; and therefore the impulſion they receive, will be 3600 times leſs than thoſe received by the frigate, allowing the wind to blow with the ſame force, and the effort of the wind to overſet the ſhip, will be 216,000 times leſs. But the force which the weight of the ſmall ſhip has to recover or right herſelf, is likewiſe 60 times leſs, for the weight itſelf is become 216,000 leſs, and when applied to a lever, 60 times ſhorter, it ſhould have 1,296,0000 leſs relative force. After this, it is no ways ſurpriſing, that the ſmall ſhip which has 60 times leſs force, in proportion to the *Gazele*, to ſuſtain the preſſure of the ſails, ſhould not for one moment reſiſt the effort of the wind, not even when great part of the ſails are furled; and ſeveral other expedients tryed by many who intereſt themſelves too much to preſerve theſe proportions, and ſave, if poſſible, the credit of the common rules. I fairly own that the model I made overſet likewiſe ſeveral times; becauſe, as I obſerved before, I ſatisfied myſelf in making the dimenſions of the maſts, nearer to the true, only in retrenching ſimply the principal defects in the common eſtabliſhment; and the wind at the ſame time blew in heavy ſqualls, but the other ſmall ſhip, after they had reeft part of their ſails, overſet 20 or 30 times to one of mine, which is a plain proof that the maſts ſhould not be proportionate to the other parts of the ſhip.

In the ſeventh chapter, he treats of the names and uſes of the ropes, which conſtitutes the ſtanding andrunning rigging; which concludes the ſecond ſection.

In the third ſection, he treats of the abſolute relative force of ſolids, whether wood, iron, or any other metal uſed in ſhipping, and endeavours from thence to make a general rule, for determining the ſcantlings at every particular piece of timber in a ſhip: He alſo conſiders, whether the common methods are ſufficient for preventing a ſhip's hogging or cambring; this takes up four chapters; but as M. *Duhamel* has given us a table

table of ſcantlings and dimenſions, we refer our readers to the Appendix for determining that point.

In the fifth chapter, he gives us the following account of the ſolid of leaſt reſiſtance; that is, ſuch as is not liable to be broke in one part more than in another.

Seeing it is certain, that in all bodies whoſe elementary ſlices form ſimilar figures, the relative reſiſtances are in proportion to the cubes of the diameters of their thickneſs, we may from that principle determine the figure of the ſolid of leaſt reſiſtance, that is ſuch as is not liable to be broke in one place more than in another.

Suppoſe a power applied to the top A of the body A B, *Fig.* 9, and acts at the upper end in the direction A G, perpendicular to the axis of the ſolid, of which all the elementary ſlices are ſuppoſed to be either ſquares, or cylinders; this power will have more or leſs relative force to break the body according to its diſtance from that part which bears the greateſt ſtrain. If that part be near to the top, the relative force of the power acting on A will be weak, but ſtronger when at a greater diſtance; it will always be proportionate to that part of the axis A C, which ſerves as a lever to the power: Now the relative reſiſtance of ſolids, which are as the cubes of their diameters, ſhould be equal to the relative efforts of the power that preſerves the equilibrium; ſo the cubes of the diameters at different parts of the lengths, ſhould be in proportion to the lengths of the parts of the axis; conſequently the ſolid of equal reſiſtance in all its parts, ſhould be a conoid formed by the firſt cubick parabola. A power at eight times the diſtance will have eight times the effort to break the ſolid, on which account the diameter at that place muſt be double that which is at the top, where the power is ſuppoſed to act. If the power is 27 times the diſtance, it will have 27 times more purchaſe; but if the diameter at that place be three times bigger, it will be able to ſuſtain that whole weight.

We need not obſerve that this ſhould be the figure of maſts; it will be proper here to ſhew how this cubick parabola may be deſcribed, which may be done by the following method, delivered to us by our author.

Divide the length into 64 equal parts, and the diameter at the partners, into four equal parts. In order to determine the diameters at theſe ſeveral parts of the length; at 27 parts of the length, the diameter is three fourths of that at the partners; at 8 of the length of the diameter, half that at the partners, and at the firſt diviſion of the length, the diameter one fourth of that at the heel,

Note,

Note. The parts of the length are accounted from the top, and in order to find the intermediate points betwixt these, see the following table.

Parts of the length.	Diam.	Parts of the length.	Diam.	Parts of the length.	Diam.	Parts of the length.	Diam.
60	3.91	45	3.56	30	3.11	15	2.47
55	3.8	40	3.42	25	2.92	10	2.15
50	3.68	35	3.27	20	2.71	5	1.71

In regard to the yards, they ſhould not have the ſame figure, they ſhould terminate in a point at each end, and each half ſhould be formed by the revolution of a ſecond cubick parabola. It is eaſy to perceive the reaſon of this difference; that power which tends to break the yards is not only applied at a leſs diſtance towards the extremities, but is alſo leſs, becauſe the effort of the ſails being diſtributed the whole length of the yard, there will be only that force which exerts itſelf on each part of the yard. The whole effort which the maſt ſhould ſuſtain, is applied at the top, ſo it is always the ſame abſolute force which tends to break the maſt; whereas in the yards, the abſolute force is greater towards the middle: The middle of the yard has not only the greateſt effort to ſuſtain, but this force is likewiſe applied at a greater diſtance. If we examine the effort of the ſail at one quarter of the length of the yard, we ſhall find it but one half of that which it is at the middle, and, beſides, the center of its effort is applied but at one half of the diſtance. In one word, the relative forces which tend to break the yards are, as the ſquare of their diſtances from the next yard arm, and as the reſiſtance ſhould be in an equilibrium with theſe forces, it muſt follow that the cubes of the diameters be in proportion to the ſquares of the diſtances from the yard arm. Hence, if we divide half the length of the yard into 64 equal parts, and the diameter at the ſlings into 16, the diameter at 27 parts of the length accounted from the yard arm, muſt be nine ſixteenths of that of the ſlings; at 8 parts of the length, the diameter muſt be one quarter of that at the ſlings, and at one ſixty-fourth of the length, the diameter muſt be one ſixteenth of that at the ſlings.

Our author, then conſiders the maſts that ſhould be made of ſeveral pieces, being too large for to be made of one tree, and thinks they ſhould be of a different form; at the ſame time, he tells us, the mariners do not conform to any of theſe proportions; and that they are as much deceived, in reſpect of the figure, as in the length; though, they are very ſenſible, the figure of maſts ſhould differ from that of the yards. The builders, however, ſays he, have found to as great perfection as poſſible the proportions the diameters should bear to the other dimensions; for when they discovered the weakest part, they have made them bigger at that place, and, by the mere dint of repeated trials, have brought that point to as great perfection as could have been done, by the assistance of geometry.

In the sixth and seventh chapters, he considers the strength of the cordage, which concludes the first book.

In the second Book, he considers the ship when a float, and at rest.

In the first section, which he divides into six chapters, he treats of the weight of a ship, and the force of the water to sustain that weight.

The first three chapters are chiefly employed in prescribing rules to ascertain the precise draught of water a ship should draw, when properly loaded; which he performs by measuring the immerged part, and thereby discovers if her load-water line corresponds to that in the draught; the substance of which M. *Duhamel* has extracted, for which we refer to the Abridgment, Chapter VIII.

The other three chapters are wholly taken up in gauging of ships, and determining their tonnage, either in weight or bulk, and regulating the fees for anchorage, and other duties, which are regulated by the tonnage.

This concludes the first section; and, in the second, he treats of the weight of the ship, and the proper position of the center of gravity, and gives rules for finding it. This with his remarks, takes up ten chapters, which M. *Duhamel* has given us in his second edition, the translation of which is hereto annexed, to which we refer; but we must not pass over what M. *Bouguer*, says of the mechanick way of finding the center of gravity.

All the mechanicks, says he, know how to find the center of gravity of any body by suspending it. It is worthy to be remarked, continues our author, that this method may be very useful, and easily executed in the naval arsenals, where they have ready prepared every thing that is necessary for that purpose: All that is required is only to make a block of wood exactly similar to the immerged part of the ship, and proportioning all the parts of the block to the corresponding parts of the ship, by a scale of one fourth or one third of an inch, or any other convenient space, to one foot of the corresponding parts of the ship; care must be taken to have the wood as light as possible. The block being thus prepared, may be suspended by a piece of packthread, in different situations; if we conceive the packthread produced, it will point out the center of gravity. Notwithstanding the simplicity of this practice, our author says, it will be convenient

convenient on some occasions to use other methods, which may be more directly applied towards finding the center of gravity.—Thus far our author.

We shall here add, that some useful discoveries may be made by models, or blocks, and this, we conceive, with as great certainty as by calculation; for it must be allowed by the nicest calculators, that the *data* taken from the draught of a quarter scale, may be liable to great errors; but, upon strict examination, we may venture to assert, that there are very few ships that have both their sides exactly equal in every respect, and there need be no more convincing proof of this, than suspending the block by a piece of pack-thread fastened to a hook in any part of a strait line, drawn from the middle line of the stem to that of the post. This hook may be moved forward and aft to different places in the middle line, and a plumet suspended from the upper part of the midline of the stem, and another from the] upper part of the middle line of the post, if the two sides be exactly of equal dimensions, and likewise homogene, they will be of equal weight: A plane passing through these three lines, whatever part of the middle line the hook be in will likewise pass through the middle line of the keel, stem, and post; a block that will stand this proof may be truly said to be a most valuable piece of workmanship, executed to the greatest possible perfection, and may be deemed the master-piece of the art, and must redound to the great honour of the workman.

The block being thus provided, and suspended by the hook, the plumb-lines at the stem and post at the same time corresponding to their middle-lines, and to that which suspends the block, we may hold a batten out of winding, a term well known to the shipwrights, with the line that suspends the block, and with a pencil draw a line on the block; a plane passing through this pencil line, at right angles to the keel, and passing likewise through the line that suspends the block, will likewise pass through the center of gravity, which, therefore, must be somewhere in this plane; again, move the hook to some other part in the middle line, and let the block be suspended from that point; draw also another pencil line out of winding, with this last line of suspension: The intersection of the two pencil lines will give the height of the center of gravity above the keel, and likewise its distance from the post and stem; and if the hook be moved to any other parts in the midline, and a pencil line drawn as before, it will likewise intersect in the same point, or let there be never so many points assumed in the middle line, and the block suspended by each, and pencil lines drawn, they will all intersect in the same point, and as the center of gravity will always be in that plane which passes

 through

through the middle line of the keel, ſtem, and poſt, it may, with certainty, be marked on the draught.

It muſt be allowed this will require the utmoſt nicety, and, if well executed, will agree exactly with that found by calculation, provided the dimenſions be taken with an exceeding good ſcale of equal parts, for which we judge the diagonal ſcale of equal parts in Plate II. of the foregoing Treatiſe to be ſufficient.

Having thus found the center of gravity of the immerged part, we may, by the like proceſs, find the center of gravity of the whole ſhip, compleatly rigged, maſted, and with all her guns, ammunition, proviſions, &c. on board. In order to which the model muſt be compleated, her upper works, &c. ſimilar to the ſhip, maſted, rigged, and have the ſame number of guns, ſhot, caſks, caſt ballaſt, in ſhort, every particular ſpecies that compoſe the whole weight of the ſhip, all ſimilar to the reſpective ſpecies in the ſhip, that is, in proportion to the cubes of their ſimilar dimenſions. All theſe things being ſtowed in the model, they may be ſhifted fore and aft, higher and lower, till ſuch time as by repeated trials the center of gravity of the whole ſhip may be properly ſituated with reſpect of that of the immerged part.

It muſt be allowed this will require the utmoſt care in the execution, but it muſt likewiſe be allowed, it will require no leſs care and accuracy to find the exact dimenſions of the ſeveral ſections of the ſhip, eſpecially as every dimenſion in the ſhip is 48 times bigger than their ſimilar ones in the draught, ſo that an error of a quarter of an inch in the draught, which is only the 48th part of a real inch in the ſhip, will occaſion an error of 110592 cubick quarters of an inch in the ſhip, provided the error be in all the three dimenſions, *viz.* length, breadth, and thickneſs.

There are ſeveral models compleately maſted, rigged, with guns, anchors, &c. proportioned to thoſe of the ſhip; ſuch as have theſe in poſſeſſion may make ſeveral uſeful experiments in water; a few of which we ſhall mention.

Firſt, to find the whole weight of a ſhip when properly loaded to the propoſed water-line.

To attain this, let the loadwater line be drawn with a pencil on the model, and loaded till that line come exactly to the water's edge, after which take the model out of the water, and let it be ſuſpended till all the water drains off, and then weighed. The following proportion will give the weight of the ſhip; 1 is to the weight of the block, as the cube of 48 is to the weight of the ſhip. *Note*, this may be done without the maſts, and the block may be loaded with ſand, or any other ponde-

ponderous body, that will sink the model to any proposed draught of water. If the weight of the ship be given, we may find what the weight of the block should be by the reverse of this proportion. We shall illustrate this by an example.

Example. Admit a model, when properly loaded, weighs 163 ounces, what will be the weight of the ship in tons?

As 1	0.
Is to 48^3	5.043723
So is 163	2.212188
	7.255911
Subtract	4.554368
Tuns 503	2.701543

As the index of this logarithm is 7, the natural number must consist of eight places, and the answer will be in ounces, which cannot be had in the common tables. We shall therefore reduce them to tons by the common rules of reduction. First divide the ounces by 16, gives pounds; divide the pounds by 112, gives hundreds; lastly, divide the hundreds by 20, and we have the answer in tons. Now all this may be done by subtracting the sum of the logarithms of these three divisors from the sum of the logarithms of the first and second term, as in the preceding operation.

16	1.204120
112	2.049218
20	1.301030
Sum	4.554368

Hence we have the following general rule: To the logarithm of the weight in ounces, add the constant logarithm of 48^3, which is 5.043723, and from the sum subtract the constant logarithm 4.554368; the remainder will be the logarithm of the number of tons. It must be observed, that if the scale be not a quarter of an inch to a foot, we must not take the logarithm of 48^3, we must find how many of the parts that represents one foot in the draught will make a real foot; as for instance, if the draught be a three eighth scale, it will take 32 of them to one foot, so that in that case we must take the logarithm of 32^3; if by a half inch scale, the logarithm of 24^3; if by a three quarters, the logarithm of 16^3, &c.

Secondly, we may, by the same rule, find the weight of the ship when launched: It is only loading the block to the same draught of water with the ship when launched, and then taking the weight in ounces, and

and use the same process as before; we may repeat the same when ballasted, when rigged, in short, we may find the weight of the masts, guns, provisions, &c. or how much weight will be necessary to be put on board to make her draw an inch more water. It must be understood that this rule will give the tons, in the common acceptation of that word; for by that is meant the builders tons; for finding which there is an established rule, which may vary according to the custom of the place she is built in. The freight of goods in the merchant service is either in weight, or bulk; the weight is 20 cwt. to one ton, and 40 cubick feet make one ton.

The general rule for determining the tonnage of ships taken into his Majesty's service.

1. Let fall a perpendicular from the back of the main post at the height of the wing transom, to the rabit of the keel produced.

2. Set forward for that two inches and a half for every foot in height for the rake of the post, and from that point measure to the perpendicular let fall from the foreside of the stem, observing, if the ship is not on an even keel, to make use of a square applied to the base board.

3. Deduct three fifths of the extreme breadth out of that length, the remainder is accounted the length of the keel for tonnage.

4. Multiply this length by the extreme breadth, and this product by the half breadth; divide this product by 94, the quotient will give the required tons; or, which is the same thing, multiply the length of the keel by the square of the breadth, and divide the product by 188; the quotient will give the tons.

Example. Keel for tonnage 144.5 feet; breadth extreme 51; required the tons? The following is the operation performed by logarithms:

51^2	3.415140
144.5	2.159868
	5.575008
188	2.274158
1999 tons	3.300850

(See this operation performed by the sliding rule, p. 99 of the foregoing Treatise.)

In the merchant service take the depth of the keel below the rabit, and set that off from the rabit of the post, then proceed as before; for boats, in general, proceed from the back of the post, and proceed as above.

It is the general practice of the builders to measure the tonnage by the real dimensions of the ship, when upon the blocks. The builders and mariners agree in this point, and experience proves beyond dispute, that few,

few, if any ships, are exactly similar to the draughts; and, indeed, it is impossible they should, unless the thickness of the plank be laid down in the draught, which, perhaps, may be one of the most intricate operations in the practical part of ship-building; however, I shall attempt it in another place. The chief design of laying down the proposed dimensions on paper, and then in the loft, is to determine the exact form and bevelling of every timber in the ship, which is now done to so great perfection in his Majesty's dock-yards, that they want very little reconciling when going to be planked. As there is scarcely a possibility of ascertaining the true dimensions from a draught, it seems there can be no great dependance on the calculations mentioned by our author. He has, to his great honour, carried his investigations to the utmost nicety; having considered the minutest circumstances, and the alterations the ship undergoes in all different situations, and has brought the theory of ship-building to as great perfection as the nature of the subject will permit, though very few shipwrights can follow him in his deep researches.

Our author, in the eleventh chapter, shews how to find, by a simple experiment if the center of gravity of a ship be properly situated, even after she is built.

It would, says he, undoubtedly be of great advantage, after a ship is built, rigged, and loaded, to have it in our power to be well assured, even when she is in the harbour, that the center of gravity be properly situated with respect to the metacenter.

Sometimes there are many things ranged and placed in a very different manner. The consumption of ammunition and provisions in a long voyage is very considerable, and it will be necessary to know what changes result from thence; and this is what may be had by a very simple experiment. We are obliged for the first idea of this to Father *Hoste*.

If we place a weight P, on the outside of the ship O E C, *Fig.* 10, at the outer end Q of a sparr, laid across the ship, this will make the ship incline to a certain point, at which time there will be an exact equilibrium betwixt the weight suspended without the ship, and the whole weight of the ship, on each side of the line Y Z, in the direction of the vertical effort of the water. The common center of gravity G, is in the same vertical with the metacenter, when the ship is in an horizontal situation; by the metacenter our author understands that point, above which the center of gravity should never be placed. The more the ship inclines, the further will the center of gravity G be removed from the line Y Z, the vertical of the metacenter, and it is plain that G T, the distance from that line, is always in proportion to the sine of the

the inclination ; at leaſt, when the inclination is but ſmall. Now if that diſtance, and likewiſe the whole weight of the ſhip be known, we have likewiſe its moment, or the relative force with which that weight acts, in endeavouring to right the ſhip, and bring her again into an horizontal ſituation; but ſince both the ſituation, and likewiſe the weight that produces the inclination are known, we may from thence know if the moment of one be equal to that of the other, and thereby eaſily diſcover if the center of gravity be in that very point we propoſe.

We cannot be too nice in taking the quantity of the angle of inclination, for the ſucceſs of the whole experiment depends on this: To attain this, we may uſe a level line for the ſenſible horizon of the ſea, or a plumb-line faſtened to the head of the maſt, and take its diſtance from the foot of the maſt, both when the ſhip is upright, and likewiſe when ſhe heels; the plumb-line ſeems to be the moſt convenient, becauſe we have thereby immediately the proportion in which the center of gravity recedes from the vertical of the metacenter, which will always be in proportion to the diſtance of the plumb-line from the foot of the maſt. We muſt be very careful, during the whole time of the operation, to render all the circumſtances abſolutely the ſame, that we may be well aſſured the inclination is produced only by the weight applied to the outſide of the ſhip: No doubt, this will require the aſſiſtance of many hands, to put every thing requiſite in its proper place, but they muſt all withdraw, when the diſtance of the plumb-line and the other dimenſions are meaſuring. The weight of two or three, or ſometimes even ten men, need not be regarded; whereas the weight of the whole crew would produce a very ſenſible alteration; and, I conceive, the crew might be diſpoſed to great advantage in this experiment, as they may be eaſily moved from one place to another.

We may, by this means, find the center of gravity of the ſhip, provided we know only the metacenter; for, having the quantity of the weight that produces the inclination, and examining R Z, its diſtance from the metacenter, or from the vertical that paſſes through that point, and on which the effort of the water exerts itſelf, we have likewiſe its moment, or its relative force, which is equal to that of the weight of the whole ſhip, ſince theſe two exactly ballance one another; ſo it is only dividing this moment by the whole weight of the ſhip, and the quotient will give us the diſtance of the center of gravity, G, from Y Z, the vertical of the metacenter. If the weight that makes the ſhip incline be 5 tons, and its diſtance from Y Z be 30 feet, its moment will be expreſſed by 150; and if this moment is divided by 1800, which is ſuppoſed to

be

be the whole weight of the ſhip, we ſhall find that the diſtance of the center of gravity is from the vertical, Y Z, one inch. After this, it will be eaſy to diſcover how far the center of gravity is below the metacenter *g*; ſince there will always be the ſame proportion betwixt the diſtance of the plumb-line from the foot of the maſt, and the height of the maſt, that there is betwixt G T, one inch, the diſtance of the center of gravity, G, from Y Z, the vertical of the metacenter, and *g* G, the diſtance betwixt the metacenter and the center of gravity. If a plumb-line, of 50 feet long, is one inch diſtant from the foot of the maſt, we have this proportion, 1 : 50 : : 1 (inch, the diſtance of the center of gravity from the metacenter) : 50 inches, which makes G *g*, the diſtance of the center of gravity, below the metacenter 4 feet 2 inches.

We may remark, that, in order to determine this exactly, it is not neceſſary to know the preciſe point in which the metacenter lies; it may be ſuppoſed in the middle of the breadth-line O C on the upper deck.

The ſmaller the weight is that makes the ſhip heel, ſo much the greater muſt be its diſtance from the ſhip; however, an error of ſome inches, in the horizontal diſtance of the weight, will be ſcarce perceptible.

In fine, where neither the ſituation of the center of gravity, nor of the metacenter, is known, this experiment will at leaſt have one conſiſiderable advantage, that thereby we may know if theſe two points are always ſituated in the ſame proportion with reſpect to one another. We may, by this means, be in condition to reap the profit of all experiments made in former voyages, and eaſily find the ſhip's beſt ſailing trim, which the mariners call her ſeat in the water; and it is only by theſe repeated trials, that hitherto they have found it out. Though the builders always draw a water-line on their draught, to determine the preciſe draught of water the ſhip will draw when loaded; it is but too true, that they have no certain method to aſcertain this, and are altogether ignorant what ſhould be the difference of the draught of water afore and abaft.

All ſhips have a ſcale of feet and inches on their poſt and ſtem, to determine the draught of water afore and abaft: We may, by this ſcale, diſcover if the whole weight, and if the goods be ſtowed exactly in the ſame manner, with reſpect to the length of the ſhip, and likewiſe if the center of gravity be properly ſituated in reſpect of fore and aft. But tho' theſe be important diſcoveries, yet theſe alone are not ſufficient; for, admitting we have all theſe, the center of gravity may be either too high or too low; to aſcertain which, we muſt have recourſe to the preceding experiment. Thoſe who have the charge of navigating the ſhip, and ſtowing the goods, make particular mention in their journals, of the weight of the cargo, the number of guns, the exact draught of water fore and aft; they need only make one remark more, which is, to ſpecify the exact weight that will be neceſſary to be laid on the outſide, in order to make her heel to a certain determined point.

When all this is given, it ſeems we know all the circumſtances of the weight, which contributes to the ſafety and perfection of navigation; for what more can be deſired, but the exact quantity of that weight, and the preciſe point in which it is united. It does not appear that the mathematicians who have examined this ſubject, have proceeded on any other ſuppoſition, than to render our examination compleat: Theſe reſearches muſt be carried further. The weight of the ſhip may be exactly the ſame, and the center of gravity may likewiſe be ſituated in the ſame point, with reſpect to its height, and yet produce different effects. The effect will be exactly the ſame while the ſhip continues in the ſame ſituation; but it will be quite different, when the ſhip begins to rowl, and this may happen even in a calm, when a ſhip has no head way. If any exterior cauſe, as the continual motion of the ſea, or a ſudden ſhock of the waves puts the ſhip out of her horizontal ſituation, on recovering herſelf ſhe contracts a motion which makes her incline to the oppoſite ſide, and her oſcillations continue ſometimes a conſiderable while; becauſe the exterior cauſe is renewed, and acts a ſecond time, which perpetuates the motion: This concludes the ſecond ſection.

The third ſection contains three chapters.

The firſt on the point, round which the ſhip rowls, and how far the weight will conduce to her rowling.

The ſecond. The figure of the ſhip being given, and the diſtribution of its parts, to know the direction of the oſcillations.

The third chapter is to find the changes produced on the rowling, by the tranſpoſition of ſome parts in the ſhip, with ſome remarks on pitching.

As M. *Duhamel*'s remarks contain the ſubſtance of what our author has ſaid on this ſubject, we refer our readers to our tranſlation of his tenth chapter of his ſecond edition, which is hereto annexed, and paſs on to the concluſion of M. *Bouguer*'s ſecond Book.

After expatiating on the great advantages that will accrue to navigating, by a proper ſituation of the center of gravity. He ſays, no labour ſhould be thought too great to obtain it; and that the builders, endeavouring to make two ſhips equal in point of ſailing, have made their bodies ſo exactly equal, and of the ſame figure, that no difference could be perceived

perceived in the very minuteſt article: But theſe ſhips were ſcarce out of harbour, when their difference, in point of ſailing, ſhewed itſelf in a very great degree, to the extreme amazement of all the beholders. This great difference cannot be attributed to the chimerical cauſes, for they deſerve no better name, to which they have recourſe.. Whence comes this difference, if not from the center of gravity, the ſituation of which they had given themſelves no trouble to examine, if in the ſame place in both? But granting that it may ſo; yet when the cargo is differently ſtowed, and ſhe inclines more, or rowls to a greater or leſs degree; the immerged part ceaſes to be the ſame, and of conſequence the ſhip will, in this reſpect be different, and produce different effects. It may here be aſked, if the two ſhips were to undergo M. *Bouguer*'s experiment, and the center of gravity, metacenter, *&c.* are found exactly the ſame in both; and, if then, there ſhould be any conſiderable difference in point of ſailing, whence this could ariſe? For they are ſuppoſed to be rigged exactly both alike.

The chimerical cauſes, he mentions, are, that ſome imagine that a ſhip's ſailing depends on driving wedges, in ſome particular places; on ſetting up the rigging, which may be too tight or too ſlack, on a piece of ſail being ſpread to the wind, or on a weight of 15 or 20 pound being ſuſpended in a certain place, *&c.* he ſays there are not wanting ſeamen, who not knowing the cauſes of ſuch changes, have aſcribed them to ſome ſuch cauſes, and aſſured us they have confirmed them by experience: And what is ſtill more ridiculous, it is uſual, on preſſing occaſions, to ſaw the gunwales, and to looſen ſome parts, whereby they imagine the ſhip's motion will be quicker, becauſe they are more ſenſible of her motion themſelves. This is, ſays our author, as if a poſt chaiſe badly ſlung would go faſter, becauſe they who are in it feel themſelves more ſuddenly toſt and tumbled about. What ever may be in theſe remarks of our author, we may venture to aſſert, that a ſhip, after being looſened, has got away from another that has gained on her very faſt before.

M. *Bouguer*, in his third Book, examines the laws which fluids obſerve in their ſhock; as the wind in ſtriking the ſails, and the water in encountring the fore part of the ſhip: He divides it into five ſections.

The firſt ſection has eight chapters.

In the firſt, he conſiders how the impulſion of the wind on the ſails, and the ſhock of water on the bow, contribute to the ſailing, which he treats in a moſt elegant manner, as a ſpecimen of which we ſhall give the following extracts.

When a ſhip ſails out of the harbour, ſhe acquires her motion by infinitely ſlow degrees; much after the ſame manner as heavy bodies, in their fall, arrive not at a certain velocity, but by an infinite repetition of the action of their weight.

The firſt impulſions of the wind greatly affect the velocity, becauſe the reſiſtance of the water might deſtroy them, for the velocity being at firſt ſmall, the reſiſtance of the water, which depends thereon, will be very weak; but the faſter the ſhip goes, the leſs will be the force of the wind on the ſails, whereas it is quite otherwiſe, with reſpect to the impulſion of the water, on the bow; becauſe it augments in proportion to the velocity with which the ſhip ſails. So the new degrees, which the effort of the ſails adds to the motion of the ſhip are continually decreaſing; whilſt, on the contrary, thoſe which diminiſh the reſiſtance of the bow are continually increaſing. The velocity is accelerated in proportion as the quantity added is greater than that ſubtracted; but when theſe two powers become equal, when the impulſion of the wind on the ſails, has loſt ſo much of its force, as not to act but in proportion to the force with which the reſiſtance of the water acts on the bow, in the oppoſite ſenſe; the ſhip then will go no faſter, and will ſail with a conſtant uniform motion. The great weight of the ſhip may be the cauſe of the ſhip's being ſo long in coming to her greateſt velocity; but this weight makes nothing to the degree of velocity; and when the ſhip has once come to it, ſhe afterwards goes on by her own intrinſick motion, and ſhe can neither gain nor looſe any new degree of velocity: She moves as by her own proper force *in vacuo*, without being afterwards ſubject, either to the effort of the wind on the ſails, or the reſiſtance of the water on the bow. If at any time the impulſion of the water on the bow ſhould deſtroy any part of the velocity the impulſion of the wind on the ſails will repair it, ſo the motion will continue the ſame; but it muſt be obſerved this will only be when theſe two powers act in a quite contrary direction to one another; otherwiſe, they will not mutually deſtroy one another. The whole theory of working ſhips, depends on this oppoſition and perfect equality, which ſhould ſubſiſt betwixt the impulſion of the water, and the impulſion of the wind.

In the ſecond chapter, he treats of the meaſure of the abſolute ſhock of the water, and of the wind.

When, ſays our author, the water, or any other fluid, ſtrikes a plane, every particle will act with greater or leſs force, according as the direction is nearer or farther from being perpendicular.

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The effort of one particle is expressed by the sine of the angle of incidence; but at the same time that each particle makes a greater or smaller impression, the number of these particles will be greater or smaller, according to their right, or oblique direction; and this number is likewise expressed by the sine of the angle of incidence, so the impulsion is in proportion to the square of the sine of the angle of incidence. When the angle is right, the impulsion will be the greatest that it possibly can be; whereas, when it is only 30 degrees, every particle will make only half the impression, and there will be only half the number that will contribute to the shock, so the effort will be only one quarter.

But it is not only the obliquity of the direction in which the fluid gives the shock, that makes the difference; it is likewise more or less, in proportion to the absolute velocity, which it has, independent of the obliquity: As soon as the fluid moves faster, the shock becomes greater, and is in proportion to the square of the velocity. If the water, which for example, strikes a surface, acquires three times the velocity, every single particle will act with three times the force; but as there will be three times the number that make their effort, the whole shock will be nine times greater. This is a property which is common to all fluids, which makes their efforts sometimes very prodigious. Salt-water, for example, running at the rate of one foot in a second, will have but a small effect, but if the velocity is ten times greater, the shock will be a hundred times greater; a force sufficient to break thro' the thickest dykes.

Hence, when the same fluid strikes the same surfaces with different velocities and different obliquities, the impulsions are as the product of the squares of their velocities by the squares of the sines of the angles of incidence.

If not only the velocities, and the sines of the angles of incidence be different, but likewise the surfaces; the impulsion will then be in proportion to the extent of the surface, which will, nearly, be as the product of the squares of the velocities, and of the squares of the sines of the angles of incidence, multiplied by the area of the plane, which receives the shock: I say, nearly, for it may happen that the shocks are not proportionate to the areas of the surfaces that receive them; for instance, a surface of double the area may not receive exactly double the shock, on account of the greater or less difficulty with which the particles retire after having accomplished their shock.

Be that as it will; if the preceding rules be admitted, we need only make some experiments on the shock of the fluids, by which we may judge of the force of the shock in all other cases. It may be admitted as a prina principle eſtabliſhed by experiments, that the perpendicular ſhock of ſalt water, whoſe velocity is one foot in a ſecond, upon a ſurface of a foot ſquare, will be nearly equal to one pound ſeven ounces. If the velocity be greater, the impulſion increaſes in the duplicate proportion : If the ſurfaces be greater, the effort is in proportion to their areas, and, laſtly, if the ſhock be oblique, the impulſion changes according to the ſquare of the ſine of the angle of incidence.

Upon the whole, if the velocity of water, or of any other fluid, be known, we need make no doubt about determining the force of the ſhock ; but it is not ſo with reſpect to the wind. The denſities of the air are very variable, and are ſeldom ſufficiently known ; ſo it will be better to endeavour to determine the force of the wind immediately, without perplexing ourſelves to deduce it from the velocities. There have been ſeveral inſtruments contrived by the ingenious for this purpoſe ; to thoſe who are not furniſhed with any, I recommend the following, which is very ſimple, and I found it very uſeful in practice.

This Anemometer, is only a piece of light paſte-board applied to a ſort of ſteel yards, which performs its office by a ſpring. The paſte board A B D E, *Fig.* 11, is 6 inches ſquare, faſtened to the rod C F, which is put into the pipe F G, and reſts on a ſort of ſpring in the bottom of the pipe ; the piece of paſte-board being placed directly againſt the ſhock of the wind, the rod C F will preſs the ſpring with greater or leſs force, in proportion to the impulſion of the wind. There is a rowler at F, in the mouth of the pipe, on which the rod C F moves, to take off the friction. The rod being graduated, we have the quantity of the impulſion of the wind, in pounds and ounces, in the ſame manner that the ſteel-yard gives the weight of any thing elſe ; but as the wind may be variable, the impulſion may move the rod backwards and forwards ; ſo, to eſtimate the quantity of the impulſion, we muſt take a mean, betwixt the leaſt and greateſt. One of the principle advantages of this inſtrument is, that we need only place the paſte-board parallel to the ſurface of the ſails, without regarding the obliquity of the ſhock, by this means it will be eaſier to determine the quantitiy of the whole impulſion that makes the ſhip ſail, and, from that, be able to judge whether the maſts will be in danger. I preſume it will not be ſafe to charge a foot ſquare, with a weight of ſix pounds. In *France*, the velocity of the wind is about 50 feet in a ſecond, if it be in winter ; but if in ſummer it will be about 60 or 63, and ſtill more, over all the torrid zone. This is only its relative velocity, which it has with reſpect to the ſhip, whereas, its abſolute velocity is much greater, and is ſufficient to overſet the ſhip, and if on land would

would overturn houſes, and tear trees by the root out of the ground. The reaſon of what our author advances here, I take to be, that the houſes or trees do not go from the wind; whereas, the maſt of the ſhip, before it breaks, forces the ſhip a head, and as it were, runs away from the ſtroke, which cannot be the caſe of any thing that is faſtened in the ground.

The Anemometer may likewiſe ſerve to meaſure the effort of the water, as well as that of the wind. In the builder's yards, where they have every thing that is needful for the purpoſe, they may eaſily make a ſmall bow of wood, ſimilar to the bow of the ſhip, and then, inſtead of the paſte-board A B D E, *Fig.* 11, fix this ſmall bow to the rod C F, which being expoſed to the ſhock of the water, we ſhall then have the quantity of the effort in pounds and ounces; we may ſee, by the direction of the rod, in what direction the bow receives the ſhock. Laſtly, we may repeat the experiment, by expoſing to the ſhock of the fluid, a plane equal to the baſe of a conoid, which repreſents the ſmall bow; by which we ſhall perceive how much the ſhock of the fluid is leſs on the bow, than on the midſhip frame. Theſe mechanick experiments may help us to judge of the impulſions which ſurfaces receive in moſt caſes; but the general method is, to reduce the impulſions which curve ſurfaces receive, to thoſe which fall on plane ſurfaces, in order to which the curves muſt be divided into ſuch a number of ſmall parts, that they may be deemed ſtrait.

In the third chapter, the impulſion of fluids, on different figures, is conſidered; at firſt on a bow formed by two ſtrait lines.

Let the bow B A D, *Fig.* 12, be formed by the two ſtrait lines A B, and A D, and the direction of the ſhock be in an infinite number of lines parallel to the axis A C. The angle of incidence will be equal to the angle B A C, or to half the angle B A D, and, if we multiply each ſide A B and A D, by the ſquare of the ſine of the angle of incidence, we ſhall have the whole abſolute impulſion which exerts itſelf on each ſide, in the perpendicular direction of the line E F; let this be repreſented by the ſpace E F, and form the parallelogram E G F H. The ſides E G and F H, are parallel to the axis A C, and the other two ſides perpendicular to it. It is plain, that E G and F H repreſent that part of the impulſion which exerts itſelf in a direction parallel to the axis; and it is as plain that it will be leſs than the abſolute impulſion, in proportion as B C is leſs than A B. Since the triangles A B C and F E G, are ſimilar B C : A B : : E G : E F; ſo, inſtead of working for the abſolute impulſion on the ſides A B and A D, which partly deſtroy one another, we need

need only work for the direct relative impulsions, which act in the direction of the axis, and mutually assist one another; but we must not multiply the square of the sine of the angle of incidence by the length of each side, A B and A D, for this would give us the absolute impulsion; we must multiply the square only by C B, or C D. By this means, we have the two direct relative impulsions; and then, if we multiply the square of the sine of the angle of incidence, by the whole base B D, we shall have the relative direct impulsion on the whole bow.

If the angle at A, formed by the two sides, be 60 degrees, the angle of incidence will be 30; and its sine, being half the sine of 90, the square of this sine will be four times less; whence the direct impulsion which the bow receives, will be but one quarter of that received by the base B D, since the angle of incidence is 45 degrees, and the square of it is half the square of the sine of 90 degrees.

He then considers the impulsion of the water on a bow, formed by a semicircle, and likewise on a parabolick bow, which concludes the chapter.

In the fourth chapter, he gives a general method of finding the impulsion on curve lines, which he introduces with the following preface.

The impulsion of fluids on several other curve lines may be had by an analysis purely geometrical; but it will be necessary to have recourse to algebra in these researches, as it is only by this means we can extend our views; for what is proved this way will be universal. We conceive then, that, instead of dwelling any longer on an examination which can only be applied to particular cases, we should aspire to make our discoveries general, which may be applied to all sorts of curve lines that can receive the shock of fluids.

Of the Impulsion of Fluids in respect of the Axis.

Let B A D, *Fig.* 13, be a curve line; A C its axis, A B and A D the two branches perfectly equal; let x be the variable parts, A C or A H of the axis, and let y be the corresponding ordinates B C and E H; let dx express the infinitely small parts H b of the axis, and dy express E F, the difference of the ordinates. Again, that I may not have occasion to return here a second time, I suppose the fluid to move in the oblique direction of the lines L e I, L e I, which make the angles F e I with the axis of the curve, or with the line e F, which is parallel to the axis. Let n represent the sine of 90 degrees, m the tangent of the angle F e I; then $\sqrt{n^2+m^2}$ will be the secant of the same angle.

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The angle F *e* I is the oblique angle the ſhip's true courſe makes with the keel, or the lee-way; now, ſuppoſing the curve B A D be the projection of the bow upon an horizontal plane, and A its extremity, the angle of incidence will be E *e* I, and will be greater on that ſide of the the curve where the fluid ſtrikes it more directly, than on the other ſide, where it is more oblique. From the point I, let fall the perpendicular I K, on the ſmall part E *e*, ſo ſhall I K be the ſine of the angle of incidence to the radius *e* I.

In order to find I K, the ſine of the angle of incidence, our author has a very intricate algebraick inveſtigation, by fluxions, and as it may be preſumed, many of our readers are not ſo well verſed in algebra as to follow him in theſe deep reſearches; I ſhall endeavour to explain the whole by right angled triangles.

All that he propoſes by this long proceſs, is, to find I K, the ſine of the angle incidence E *e* I.

The angle F *e* I, the lee-way, is given, which ſuppoſe 11° 15′; then the angle F I *e*, its complement, will be 78° 45′.

Let E F be 40 equal parts, and F *e* 50 equal parts; then E F : F *e* :: R : tan. angle I E K = F E K, now ſubtracting the angle I E K from 90 degrees, we have the angle E I K, and this laſt angle ſubtracted from the angle F I *e*, there remains the angle K I *e*. The angles being thus found, our next buſineſs is to find the ſides E *e*, K I, and *e* I.

In the right angled triangle I F *e*, R : ſec ∠ F *e* I :: F *e* : *e* I; again, in the right angled triangle I K *e*, R : ſine ∠ I *e* K :: *e* I : I K, the ſine of the angle of incidence. Laſtly, to find E *e*, the ſmall portion of the bow which receives the ſhock; in the triangle F E *e*, R : ſec. ∠ F E *e* :: F *e* : E *e*. *See this operation by the logarithms.*

E F	40	1.602060	Angle F I *e*	78°	45′
F *e*	50	1.698970	Angle E I K	38	40
R			Angle K I *e*	40	05
Tan. 51° 20′		10.096890	Angle K *e* I	49	55
Com. 38 40					

R	
Sec. ∠ F *e* I 11° 15′	10.008426
F *e* 50	1.698970
I *e*	1.707396

R	
Sine ∠ I *e* K 49° 55′	9.883723
I *e*	1.707396
I K	1.591119

R	
Sec. ∠ F E *e* 51° 20′	10.204267
E F 40	1.602060
E *e*	1.806327

Having thus found I K, the ſine of the angle of incidence, and E *e* the part which receives the ſhock, multiply this laſt, by the ſquare of the angle of incidence, and the product will be the abſolute impulſion, as by the logarithms.

I K	1.591119
	2
	3.182238
E *e*	1.806327
	4.988565

The angle of incidence, on the other ſide, will be 27° 25′, the ſine of which we may find by the ſame proportions.

I ſhall only remark on the whole, that our author ſuppoſes the angle of the lee-way to be known, on which the reſult of the whole proceſs depends; and as there is yet no expedient found to aſcertain that angle, even to a quarter point of the compaſs, it is to be feared we ſhall gain very little by this general rule, therefore it is needleſs to detain our readers on this ſubject, as the concluſions drawn from them are no ways to be depended on. Our author indeed attempts to determine the lee-way, which we ſhall conſider in its proper place.

The inference he gives, from the preceding proceſs, is the reſolution of this ſurpriſing paradox, as he calls it, which is, that the relative direct impulſion depends neither on the nature of the curve which receives it, nor on the length of the axis A C, but only on its extreme breadth B D.

Let the curve B A D be an arch of a circle, parabola, or hyperbola; let it be a geometrick or mechanical curve, *&c.* ſo the breadth continues ſtill the ſame; the impulſion it receives, in reſpect of its axis, by a fluid which ſtrikes it at an angle of 45 degrees, will always be the ſame, and equal to half the ſquare of the ſine of 90 degrees, multiplied by D B the breadth; in other words, it will be half of that which D B would receive, ſuppoſing the fluid ſhould ſtrike it perpendicularly; ſince that ſtrait line may be conſidered as the curve B A D, ſuppoſing the axis to be infinitely ſmall.

Admitting all this, our author does not tell us how to apply this to the formation of the ſhip's body, nor yet how his angle of 45 degrees is to be found.

In his fifth chapter, he conſiders the impulſion of fluids on curve ſurfaces, particularly on a conick bow, and on a conoidale bow, formed by the revolution of an arch of a circle, which he inveſtigates algebraically, and

and from thence infers, that a bow, formed by half the revolution of a quarter of a circle, meets with double the resistance in an horizontal that it does in the vertical, and concludes, that by consulting the trigonometrical tables, we shall find the whole or absolute resistance, which is composed of these two relative impulsions, exerts itself in a direction, which makes an angle of about 26° 34′ with the horizon.

In his sixth chapter, he gives a method to find the impulsion on curve surfaces, by dividing them into a number of equal parts, which may be deemed plain surfaces, for which we refer to our Appendix, translated from M. *Duhamel's* extracts.

In his seventh chapter, he has some remarks on the change of the impulsions on curve surfaces, when the fluid alters its direction, and observes, that without perplexing ourselves with examining all the oblique courses a ship may sail, it will be enough to calculate the resistance, when she sails in the direction of the keel. It is certain, says he, that the angle the ship's course makes with the keel amounts to an angle of 45 degrees or 54° 44′, to loose the advantage of the figure, and still less, to change it to a disadvantage. I have, continues our author, in a memorial, communicated to the Academy of Sciences in 1733, proved this truth *a posteriori*. When a plain surface, exactly circular, is exposed to the perpendicular shock of a fluid, the nature of such a conoid that should cover it in such a manner, as thereby to meet with the least possible resistance, has been discovered long ago; but this is limited to perfect conoids alone, and besides there is room to believe that it will not be the same in a direct and oblique course. In order to clear this point, which has embarrassed the greatest mathematicians, I not only assumed any figure for the base, but even supposed the fluid to strike it obliquely, and was well recompensed for my labour, for I thereby discovered, that tho' the conoids of least resistance be different for different bases, yet it will be the same thing in respect to the impulsion, whether the course be direct, or oblique to the keel. Hence, says he, we may be excused from calculating the resistance in oblique courses, for it may be attained by calculating the resistance in a direct course. We presume, our author means, whatever be the form of that bow that will meet with least resistance in a direct course, will likewise be the form of that which will meet with least resistance in oblique courses.

In the eight chapter, he pursues the same subject, and considers the lateral impulsion, which he concludes with the following remark.

The bow that meets with least resistance in a direct course, not only meets with least resistance in oblique courses, but is that likewise which is least ſubject to drive to the leeward, which is a double advantage gained by forming the bow ſo as to give it that figure which will meet with leaſt reſiſtance in moving thro' any medium.

We have now given our readers a ſpecimen of our author's method of examining the laws which the fluids obſerve in their ſhock; the wind in ſtriking the ſails; and the water in ſtriking the fore part of the ſhip, which he compriſes in the firſt ſection of his third Book. He proceeds, in the ſecond ſection, by the ſame method, to attempt a general ſolution to all the problems relating to working a ſhip.

In the firſt chapter, he conſiders the velocity of the ſhip's ſailing, in proportion to the velocity of the wind.

It has been always ſuppoſed, continues our author, that the velocity of the ſhip has no proportion to that of the wind. M. *d'Ons-en-Bray* was the firſt who thought this ſubject worthy of our attention, and it ſeems, has deſigned to reſerve the reſolution of this queſtion to himſelf; the principles he was to proceed upon, can only be executed by experiments taken at ſea; but I attempted a direct ſolution of the problem; and, continues M. *Bouguer*, as this is entirely my own, I ſhall give the following account of it:

Let a ſhip be 163 feet in length from the ſtem to the ſtern-poſt; the exreme breadth 44 feet 9 inches from out to out. I found the area of the vertical ſection perpendicular to the keel to be about 691 ſquare feet. This ſection would receive the whole impulſion of the water, ſuppoſing there was no bow; but by reaſon of the convexity of the bow, the impulſion will be much leſs; the only difficulty will be to determine how much leſs it will be.

In examining a ſmall ſhip at *Croiſic*, I found the ſhock of the water on the bow to be one ſixth and an half of that on the plane of the vertical ſection. The area of that plane carefully meaſured was 6687 ſquare inches; the impulſion it received 66,870,000, whereas, by dividing the bow into 18 triangles, and adding up all the particular impulſions of each triangle, the whole ſum was 10,245,735, nearly the $6\frac{1}{2}$ part of 66,870,000; for $10,245,735 \times 6\frac{1}{2} = 66,597,277.5$.

I imagine that in ſhips of war it will be leſs, and may be reduced to the ninth part, ſo that we may take 77 inſtead of 691 ſquare feet for the area of the midſhip frame. But having occaſion myſelf to viſit our ſea-ports, and to know the form of our great ſhips, I was forced to acknowledge that the ſhock on the bow was only one quarter, or at moſt one quarter and an half of that on the midſhip frame. This great difference betwixt the large ſhips, and the conoid of leaſt reſiſtance, is occaſioned from this.

The

The conoid diminishes gradually from the extreme breadth, at the midship frame, which is its base; whereas, in ships, the whole breadth is continued for a considerable space, and then diminishes suddenly; which will have the same effect, as if the bow were shorter, or had less rake. In fine, according to the present form of our ships, if the area of the midship frame be 691 square feet, we may account about 150 square feet for that which receives the relative direct impulsion.

We must now consider the effort of the wind upon the sails; the area of the three sails on the main-mast, should be about 10316 square feet, and if the wind be on the quarter, most of the sails on the fore-mast will bear a part of the impulsion, on which account we may add one half more, so we have 15474 square feet for the area of the sails that receive the shock of the wind; which should be equal to the impulsion of the water on 150 square feet, as was before proved, to which the bow is supposed to be reduced; besides the densities of the two fluids should be considered, for if one fluid be double or triple the density of another, or, which is the same thing, if it be double or triple the specifick gravity, then the shock will have double or triple the force. Mercury, for example, with the same velocity will give an impulsion with fourteen times more force on an equal surface, than water; because Mercury is fourteen times heavier than water, and for the same reason water will make an impulsion 576 times stronger than the wind, because as M. *Mariotte* observes, water is 576 times heavier than air, and their impulsions are as the squares of their velocities. All this being admitted, let the velocity of the ship be 100, then 150, the square feet that receives the impulsion of the water, muliplied by 576 the density of the water, and this product by 10,000, the square of the velocity, we have 864,000,000, which expresses the impulsion of the water on the bow; and this should be equal to the impulsion of the wind on the sails, that is to 15,474 square feet; the area of the sails multiplied by 1, the density of the air, and this product multiplied by the square of the velocity of the wind, so if we divide 864,000,000, which is the impulsion of the water by 15,474, the area of the sails, multiplied by 1, the density of the air, we shall have 55,835, the square of the velocity of the wind; the square root of which, is nearly 236. As this is only the velocity with which the sails are struck, we must add to that, the whole velocity of the ship, which makes the absolute velocity of the wind 336; hence, the velocity of the wind is to that of the ship's sailing, as 336 is to 100. It must be remarked, that if instead of 576 we take 1100 for the specifick gravity of water to that of air, we shall find the velocity of the ship to that of the wind;

wind, as 100 is to 419; we ſhall take a mean betwixt theſe two, becauſe 576 and 1100, compared to unity, are near the limits of the proportion the denſity of the air bears to that of the water.

From the whole, we may conclude, that the beſt ſailing ſhip's go with two ſevenths of the velocity of the wind; when the wind blowes two or three times ſtronger, the impulſion will be four or nine times ſtronger, but the ſhip will ſail only two or three times faſter, becauſe the impulſion of the water will be four or nine times ſtronger. Notwithſtanding all our author has ſaid on this ſubject, he tells us it cannot be ſtrictly applied to all ſorts of ſhips, ſo that the beſt that can be ſaid of it is, that it may be an approximation, but ſeems to be of very little ſervice in forming a ſhip's body; I ſhall therefore, only mention the heads of what he ſays in the following chapters, with ſome remarks as they occur.

Chapter II. Of the changes which the motion of the ſurfaces produce on the ſhock they receive.

The impulſion, ſays he, will be conſiderably leſs becauſe the motion of the ſurfaces makes the fluid, as it were, looſe a part of its velocity; he concludes this chapter with examining the ſails of a wind-mill.

Chapter III. Of the changes which the motion of the ſhip will produce on the force and apparent direction of the wind.

Suppoſe, ſays he, the velocity 50 feet in one ſecond, and the force on a foot ſquare ſix pounds; the area of the ſails 15,474 ſquare feet being ſtruck perpendicularly, will receive an impulſion of 92,844; but, ſuppoſing the angle of incidence about 19 and a half degrees, the ſine of which is one third of the radius, the impulſion will thereby be diminiſhed to the ninth part; and if, by the motion of the ſhip, the velocity of the wind be diminiſhed to 25 feet in a ſecond, that is, to half the abſolute velocity, the impulſion will be four times leſs, and, conſequently, the whole will be 36 times leſs, and reduced to $3863\frac{1}{2}$ pounds.

It is plain our author ſuppoſes the abſolute velocity of the wind, the angle the wind makes with the meridian, with the keel, and with the ſails, to be given, and likewiſe the angle the ſails make with the keel, and the angle of lee-way; hence the concluſions deduced from ſuch uncertain *data* muſt be more uncertain; our readers will, therefore, we hope, excuſe us for omitting the application. We ſhall only obſerve, that in calculating the angle of lee-way, he condemns the common vanes, which, he ſays, deceive us very much in determining the angle the wind makes with the ſails, and recommends a quoit, ſuch as children play with, as better adapted for that purpoſe than any other inſtrument hitherto invented. The principle from which he calculated the lee-way, is, ſuppoſing the angle

angle the sails make with the keel be 60 degrees, and the lee-way, at the same time, four degrees, from thence he proportions the lee-way to all the angles the sails make with the keel to 30 from 90 degrees. The experience of all mariners is sufficient to confute his theory, and, it may be presumed, the rules given in our *English* navigation books, by allowing the lee-way in proportion to the sail a ship carries, may be much more depended on, as they have been calculated from the journals of the expertest mariners; for, after all his researches, he refers to experience to find out this angle of four degrees, which he calls the lee-way; and tells us, the mariners find it by setting the ship's wake in the water. This has been the subject of his IVth chapter; and in

Chap. V. he treats of the different velocities of the ship, in different oblique courses, and from his process infers, that, in order to double the velocity of the ship's sailing, she must spread sixteen times more canvass.

The VIth and VIIth chapters contain the construction of tables to ascertain the velocity of the ship's sailing, which concludes the second section.

In the third section he considers the ship with respect to her propriety of steering well, either by means of the rudder, or of the sails.

The first chapter is upon the situation and number of masts, and on the equilibrium, which should subsist betwixt the head and after sails, out of which we shall make the following extracts.

The principle, says our author, having been already established, touching the equality and perfect opposition which should subsist betwixt the impulsion of the wind, and the impulsion of the water, we may, from thence, deduce a sure method for placing the masts. If the ship has but one mast, it must be, of necessity, in the point C, *Fig.* 14, which is the intersection of the direction of the shock of the water with the keel, in oblique courses; but if in place of one we put more masts, they must be before and abaft the point C, in Z and Y, so that the sails on each side that point be in equilibrium; it is of great importance to determine this point C. According to the ordinary form of our ships, the line of direction F C intersects the keel in about two ninths of the length from afore, or nearly five sixteenths of the whole length of the ship; that is, let B A, the length from the head of the stem to the post be 160 feet, C A will be about 50, this will not answer in all ships. If the ship be formed by two cones joined at the same base, one for the fore and the other for the after part; the fore part five twelfths and the other part seven twelfths of the whole length, and the extreme breadth one quarter of the whole length, C A will then be about $48\frac{2}{7}$ of the whole

length;

length; but if the breadth DF be the ſixth part of the length A B, then C A will be only the 46th part of the length.

It muſt be remarked that theſe lengths agree only to the point C in its firſt ſituation, or firſt oblique courſes.

Without being at the trouble to find this point by calculation, it may be done by a ſimple experiment, on a model of two feet long, or on a ſhip already built, by hauling it in the harbour with a tow line faſtened to one ſide of the bow; if this line be produced it will interſect the keel in the required point C. This point being once determined, we can place but one maſt in that point, or if it be requiſite to have more, they muſt be placed on each ſide in ſuch a manner as to preſerve an equilibrium betwixt the ſails; for inſtance, if we place the maſt in Y, at leſs than the tenth part of the length from the center of effort C, without altering the other maſts, the ſails muſt be enlarged in the ſame proportion the diſtance from the point C is diminiſhed

It may be demonſtrated, that ſhips that are built on purpoſe for ſailing ſhould be made conſiderably longer, or which is the ſame thing narrower, at the ſame time the ſails muſt be narrower; and then we may have four inſtead of three ſtanding maſts; it is only by experience we ſhall diſcover if the thing be practicable; but they muſt be ſo placed that the total of the moment of the head ſails be equal to the total of that of the after ſails, on each ſide of the point C: We may eaſily diſcover if the equilibrium betwixt them ſubſiſts.

The area of the main and main-top-ſails of a ſhip of the firſt claſs is about 9500 ſquare feet, and that of the fore and fore-top-ſails, about 8040, nearly, in an inverſe proportion to their diſtances from the point C, and multiplying each area by its diſtance from the point C, we have their reſpective moments. The diſtance of the main-ſail from C is $32\frac{1}{4}$ × 9500 makes 306,375 its moment, and the diſtance of the fore-ſail $38\frac{1}{2}$ × 8040 makes 309,540 the other moment.

We may without doubt narrow the ſhips conſiderably, if we be allowed to increaſe the number of the maſts; if we have four maſts the fore-maſt Z muſt be as near as poſſible to the point A, the extremity of the bow, and two main-maſts, one in P, if poſſible before the point C, and the other in Q abaft it, and likewiſe abaft the middle of the ſhip; the ſails of theſe three will be in a perfect equilibrium, or which is the ſame thing, the moment of the two firſt will be equal to the moment of the third, obſerving, at the ſame time, to make the ſpace P Q a little more than the ſpace P Z, nearly in proportion, as the ſum of the areas of the two main-ſails is more than the ſum of the areas of of the other main-sail and fore-sail. Lastly, the mizen-mast must always be in Y, or a little further aft. The use of the sail on this mast is to preserve the equilibrium, when the sea takes the ship on the after-post, so that the point C comes nearer the middle of the ship. The sails on the bowsprit have likewise their proper use and have a contrary effect to that of the mizen.

Our author then tells us, that if we push this to the utmost rigour, we may, instead of four, have a great many standing masts, and gives us a rule for placing them properly; but as it may be presumed this is an experiment that will scarce ever be tried, I shall omit it.

The second chapter is on the figure a ship should have in order to make her steer perfectly well with her sails, of which we here subjoin some extracts.

The only means, says our author, to attain this is to make it so that I C, *Fig.* 15, the direction of the shock of the water in the oblique courses, shall always pass thro' the center of gravity G: This has put the builders under a necessity of making the fore part full, tho' they alledge a quite contrary reason for doing it; which is, that thereby a ship will divide the fluid with a greater ease; and to prove this, they tell us that fishes are broader at the shoulders and head, than at the tail, and that a mast will tow best with the butt end foremost; these pretended reasons have gained such credit as to be adopted by several eminent mathematicians; but they do not consider that the author of nature created fishes, living creatures, with a head, stomach, &c. and it is not certain that their form is the properest for dividing a fluid, since perhaps they must loose some part of that advantage, in order to gain some other of which we are altogether ignorant. As to the mast, the only reason for towing it butt end foremost, I think, is, that the rope may not slip over the end; but, continues our author, we may reconcile the whole, by saying, that this form is proper, not to make the ship sail faster, for we are sure it will have a quite contrary effect, but to make her steer well. It happens unluckily, that we must loose a little of the first advantage to gain some of the other, and as we have not arrived at that perfection, to ballance them perfectly, because they are of different kinds, we must have recourse to experience, to discover the proper mean betwixt the two: Notwithanding, our author seems here to think that making a ship full before should not be, because the form would thereby resemble that of fishes; yet, in *Page* 59, he tells us the midship frame should be placed at five twelfths of the length from afore, and gives for one reason, that thereby the immerged part will better imitate the figure of fishes; and here, after all his laborious calculations, refers us to experience, which may possibly give it contrary to his theory.

He afterwards proposes *Noah*'s ark, or the *Chinese* junks, as best formed for steering, tho' not for sailing; and, besides, they will be very subject to drive to lee-ward; and the like may be said of any other form which will make a ship steer well; and this he endeavours to prove by considering a ship formed by two cones; he chuses that figure not only to render his researches more simple, but because, he says, that figure differs little from the form of the solid of least resistance. The inference he deduces from his algebraick process, seems to be only this, that these two properties of steering well, and sailing fast, are incompatible; and, therefore, we must part with a little of the one, that we may not loose the whole of the other. I shall only remark, that the mariners have adapted a direct contrary maxim, that is, that a ship that goes well, will undoubtedly steer well, which has been confirmed to them by experience.

In the third chapter, he endeavours to determine the exact point where the extreme breadth should be placed, to render the ship more sensible of the power of the helm.

Many mechanicks, says our author, have long ago discovered, that when a power is applied to the extremity of a rod of equal weight throughout, in order to make it turn, the point of rotation will be about two thirds of the length; the rod being supposed of equal weight in all its parts; from whence our mariners infer, that the extreme breadth of the ship should likewise be two thirds from afore, without considering the case may be different. It has been the general practice to have it at that place, tho' they have by degrees drawn it nearer the middle, to render the bow sharper, and diminish the resistance; but it is certain, that, by such a change, they very much assist the action of the rudder, and herein is one of the particular circumstances, where we had better be entirely governed by experience, than by theory which continues imperfect, because it has not been pushed to a sufficient pitch; however, after a long algebraick process, he infers, that it should be placed neither at the middle, nor at two thirds, but nearly betwixt these two points, or about the twelfth part of the whole length before the middle.

In the fourth chapter is his method of knowing if the ship, that is proposed to be built, shall steer easily; or an examination of the motion which a body should take, when two powers exert their force, in contrary directions, to turn it on different sides.

The fifth chapter is only the sequel of the preceding, and, after examining the quantity and position of the sails, he concludes, that in that article, they had too much regard to the sailing, to the prejudice of her

steerage

ſteerage; to remedy which, he ſays, we muſt either give the ſhip more head-ſail, or if ſhe is not yet framed, carry the midſhip frame farther forward. This ends his third ſection.

In the fourth ſection, he examines a ſhip with reſpect to the qualities beſt adapted to make her carry a good ſail, in eight Chapters.

Chap. I. Of the mutual vertical effort formed by the united impulſions of the wind upon the ſails, and the water on the bow.

Chap. II. Of the different ſtations of the ſhip, occaſioned by the mutual vertical ſhock of the wind on the ſails, and of the water on the bow; and the conditions requiſite for properly maſting a ſhip.

Chap. III. General principles to determine the greateſt height the maſts may have, ſo as not to be in danger of being diſmaſted, with ſome remarks on the power a ſhip of each claſs has to carry ſail.

Chap. IV. The ſequel of the preceding; to determine the limits of the higheſt maſt, and the application of that rule to a ſhip of the firſt claſs, and the *Gazele* frigate.

Chap. V. After anſwering ſome objections, he examines what dimenſions of the ſails ſhould be enlarged; and if proper to make the maſts of a ſhip of different heights.

Chap. VI. To determine the moſt advantageous ſet of maſts for a ſhip already built, the draught of water being aſſumed at pleaſure.

Chap. VII. Of the form a ſhip ſhould have in regard to her girt, beſt adapted to make her carry a good ſail, and go faſt thro' the water.

Chap. VIII. Of the girt of a ſhip, in reſpect of her length, moſt conducive to make her carry ſail, with the means which may increaſe the velocity of her ſailing to a very extraordinary degree.

Our author ſuppoſes the following particulars to be known, or at leaſt attainable, by his preceding rules:

1ſt. The direction in which the ſhock of the water ſtrikes the bow: This exerts itſelf in a double capacity, for it not only endeavours, by the reſiſtance, as it were, to puſh her a ſtern, but likewiſe lifts up the bow; this angle, in his calculation, he ſuppoſes to be 48° 20′, which the line D H, *Fig.* 16, makes with the horizon.

2d. The line S K, repreſenting the direction of the wind on the ſails, that is to ſay, the angle that line makes with the horizon; for tho' the wind always moves nearly parallel to the horizon, yet the impulſion on the ſails is in a perpendicular to their ſurface, and if we conſider the whole as united in I, the middle of the ſail, the impulſion will be in a direction, perhaps not parallel to the horizon.

3d. The whole force of the ſhock of the wind on the ſail, which, he ſays, may be had by an Anemometer.

4d. The

4th. The point N, which he calls the *velique*; to determine which we are to erect a perpendicular V T to the water line, to pass thro' the center of gravity Y; the intersection of this line, with the line D H, will give the point N, thro' which S K must pass; and when the center of the effort of the wind passes thro' this point, we may, without running any risk, give the sails what extent we please; it is presumed, our author means, this should be in the middle of the main-sail, but, he says, if the mast be higher, it may be of dangerous consequence.

5th. The center of gravity of the immerged part, the center of gravity of the whole ship when loaded, and the metacenter; likewise their positions and respective distances from one another.

6th. The weight of the whole ship when loaded, and the exact draught of water. He supposes, in a first rate, the center of gravity to be two feet below the metacenter, and the center of gravity, by the inclination of the ship, to be moved four inches from the vertical passing thro' the metacenter, in which it was when the ship was upright; he likewise supposes the greatest inclination in a ship of the first rate to be 9° 30′. The inference deduced from these *data* is in page 564, that ships that are built on purpose for sailing cannot be too narrow, so their length be preserved, and asserts, that to have a ship absolutely perfect, she must be infinitely narrow, on which account she must have an infinite number of masts and sails, and, in page 566, he assures us that a frigate, which is 18 or 19 times longer than she is broad, will sail faster than the wind, and if it were permitted to reduce her to half the breadth, if then the wind staikes the sails in a perpendicular direction, the sails at the same time making an angle of 19° 30′ with the keel, the ship will then sail with a velocity not only equal to the wind, but with a velocity a third or fourth part greater than that of the wind. I shall not take upon me to follow him in these deep researches, but refer our readers to the original, as it is scarce possible, at least probable, that this should be ever reduced to practice, and so have the theory confirmed by experiments.

In the fifth and last section, he considers a ship, with respect to the velocity of her sailing, and the qualities necessary to make her keep a good wind, and drive but little to lee-ward in oblique courses. This takes up ten chapters.

Chap. I. An examination of the simplest figures which receive the least possible resistance from the mediums through which they move.

A table of the dimensions of an angular and rectilineal bows, in an horizontal sense, which meets with least resistance in passing through the water.

Chap. II.

Chap. II. Of the conoid bow, which meets with the leaſt poſſible reſiſtance in dividing the fluid.

A table of the dimenſions of ſuch a conoidal bow.

A table of the dimenſions of a new conoid, which will meet with leaſt reſiſtance.

A table of the dimenſions of two conoidals, which meet with little reſiſtance, only when they are not wholly immerged.

Chap. III. A baſe being given, to find the figure of that ſolid which ſhould cover it, ſo that it ſhould meet with the leaſt poſſible reſiſtance in paſſing through the water.

Chap. IV. Of the formation of ſeveral other bows of leaſt reſiſtance.

Chap. V. Of the bow of greateſt velocity, or of that which will render a ſhip more capable to carry ſail, and at the ſame time will divide the fluid with greater facility.

Chap. VI. To determine the figure of the bow of greateſt velocity, when it is terminated by a ſimple horizontal draught.

A table of the dimenſions of a curvi-lineal bow of the greateſt velocity.

Chap. VII. Of the figure of the after part, when it is terminated by a ſimple horizontal draught, and the method to be uſed in order to form frigates.

Chap. VIII. The ſequel of the preceding; an examination of the after part, when it is a conoid, and how to form a frigate.

A table of the dimenſions of the conoidal after part, which contributes to the greateſt poſſible degree of velocity, by the impulſion it receives from the reflux of the water.

Chap. IX. Of the form of tranſports, and of ſhips of war; and of a new form for frigates.

The firſt ſolution. When the bow is formed by two vertical planes, which make an angle.

The ſecond ſolution. When the bow is terminated by one inclined plane afore.

A particular method to form ſhips of war and frigates.

Chap. X. The ſequel of the preceding: An examination of the particular form propereſt for the bow of a tranſport.

A table of the dimenſions of a bow of the greateſt motion, which, our author tells us, differs from that of greateſt velocity in ſome caſes.

In this laſt ſection our author obſerves, that it is very doubtful whether that figure which meets with the leaſt reſiſtance in dividing the water, may be the moſt advantageous to acquire the greateſt degree of velocity; for it is poſſible that a bow, which meets with a little more reſiſtance, may render the ſhip capable of carrying a proportionate quantity of more

fail;

fail; neverthelefs, the two bows, which we may diftinguifh, by naming the one that of the leaft refiftance, and the other that of the greateft velocity, fhould have fuch an affinity to one another, that one fhould, in a great meafure, partake of the moft effential properties of the other.

He then proceeds, in his ufual method, by an algebraic procefs, to inveftigate the form of feveral bows; and, to fave his readers the trouble of an intricate calculation, has conftructed tables of their feveral dimenfions, which we fhall hereto fubjoin and illuftrate, by forming one of the curves from thefe dimenfions, which may ferve as a fpecimen for all the reft.

TABLE I. *Of the Dimenfions of an angular and rectilineal Bow, in an horizontal Senfe, which meets with leaft Refiftance in paffing through the Water.*

Height or depth.	Half Br. or Ordinates.	Height or depth.	Half Br. or Ordinates.	Height or depth.	Half Br. or Ordinates.	Height or depth.	Half Br. or Ordinates.
0	899	374	1300	778	2000	1164	2900
14	900	408	1350	826	2100	1200	3000
79	950	440	1400	873	2200	1236	3100
132	1000	471	1450	918	2300	1271	3200
180	1050	502	1500	962	2400	1306	3300
223	1100	561	1600	1004	2500	1341	3400
265	1150	619	1700	1046	2600	1376	3500
303	1200	674	1800	1086	2700	1410	3600
340	1250	728	1900	1125	2800	1444	3700

TABLE II. *Of the Dimenfions of a conoidal Bow, which meets with the leaft poffible Refiftance in dividing the Fluids.*

Abfciffæ, or parts of the axis.	Half Br. or Ordinates.	Impulfions.	Abfciffæ, or parts of the axis.	Half Br. or Ordinates.	Impulfions.	Abfciffæ, or parts of the axis.	Half Br. or Ordinates.	Impulfions.
0	308	148993	4518	2545	1949062	41862	12040	14543335
6	317	155239	5194	2791	2189549	45383	12765	15615915
20	336	167905	5943	3053	2453469	49118	13520	16837987
44	364	186165	6769	3333	2743083	53080	14304	18132351
78	400	208184	7678	3631	3059421	57280	15119	19505003
125	444	236721	8675	3948	3404528	61727	15966	20949435
185	496	268916	9767	4284	3780198	66423	16845	22478039
260	557	307900	10959	6440	4188257	71386	17755	24089705
354	626	353607	12258	5016	4630586	76624	18699	25790519
468	704	405964	13668	5413	5109155	82139	19676	27580596
604	792	466875	15198	5832	5626246	87935	20688	29463846
766	890	536439	16852	6273	6182762	94086	21736	31444132
956	999	615734	18639	6737	6792289	100524	22817	33524478
1178	1118	705619	20565	7225	7426420	107285	23936	35708216
1434	1250	807369	22636	7736	8117090	114387	25090	38001324
1729	1394	922068	24861	8272	8867188	121835	26279	40399311
2065	1550	1050881	27246	8833	9648764	129642	27507	42913773
2448	1720	1194679	29800	9421	10493903	137820	28777	45545900
2880	1904	1355015	32531	10034	11395391	146380	30085	48298823
3366	2102	1533275	35447	10675	12355760	155334	31431	51462561
3911	2316	1730807	38555	11343	13377500	164694	32818	54183109

TABLE III. *Of the Dimensions of a new Conoid, which will meet with least Resistance.*

Abscissæ or parts of the axis.	Half brea. or ordinates.	Abscissæ or parts of the axis.	Half brea. or ordinates.
0	100	5143	2593
23	122	8247	3451
55	150	10261	4632
97	183	14605	6269
155	226	20909	8559
233	280	30122	11788
340	349	43619	16379
675	552	64773	22961
962	701	93780	32478
1344	896	138926	46355
1876	1155	207366	66766
2619	1501	311931	97045
3665	1969		

TABLE IV. *Of the Dimensions of two Conoidales, which meet with least Resistance only, when they are not wholly immerged.*

When the Axe of the Bow is elevated 1000 parts above the Surface of the Water.				When the axe of the Bow is elevated 2000 parts above the surface of the sea.			
Abscissæ, or parts of the axis.	Ordinates, or half Breadths.	Abscissæ, or parts of the axis.	Ordinates, or half Breadths.	Abscissæ, or parts of the axis.	Ordinates, or half Breadths.	Abscissæ, or parts of the axis.	Ordinates, or half Breadths.
0	1045	1372	1800	0	2023	3223	3400
3	1050	1854	2000	5	2030	3825	3600
21	1070	2368	2200	14	2040	4449	3800
83	1125	2910	2400	36	2060	5093	4000
150	1175	3478	2600	89	2100	5756	4200
264	1250	4069	2800	248	2200	6438	4400
347	1300	4682	3000	433	2300	7136	4600
435	1350	5969	3400	636	2400	7851	4800
527	1400	7329	3800	1082	2600	8582	5000
721	1500	8753	4200	1570	2800	9327	5200
927	1600	10239	4600	2093	3000	10859	5600
1145	1700	11781	5000	2645	3200	12446	6000

TABLE V. *Of the Dimensions of a Curvelineal Bow of the greatest Velocity.*

First Figure.				Second Figure.				Third Figure.				Fourth Figure.			
Abscis or parts of the axis.	Ordinates, or half Brea	Impulsions.	Moments, or stability.	Abscis. or parts of the axis.	Ordinates, or half Brea.	Impulsions.	Moments, or stability.	Abscis. or parts of the axis.	Ordinates, or half Brea	Impulsions.	Moments, or stability.	Abscis or parts of the axis.	Ordinates, or half Brea.	Impulsions.	Moments, or stability.
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
126	203	146	0	356	169	31	0	200	65	7	0	125	31	2	0
399	531	333	9	712	335	61	4	400	129	13	0	250	62	4	0
627	714	406	46	871	402	71	10	703	225	23	1	500	122	7	0
758	788	425	83	1042	464	78	19	861	272	27	3	671	163	9	½
884	838	432	128	1136	493	81	26	1035	318	30	6	827	198	10	1
936	853	433	149	1200	510	82	31	1100	338	31	8	900	214	11	2
963	859	433	182	1272	526	84	38	1205	356	32	10	999	234	12	2
977	862	433	188	1310	533	84	42	1288	371	32	13	1174	266	14	4
987	863	433	193	1330	536	84	44	1333	379	33	14	1267	281	14	5
1001	865	433	199	1365	541	84	47	1401	387	33	17	1380	295	14	7
1014	866	433	204	1399	543	84	51	1466	391	33	19	1490	302	14	9

TABLE VI. *Of the Dimenſions of the conoidal after part, which contributes to the greateſt poſſible Degree of Velocity, by the Impulſion it receives from the Reflux of the Water.*

Abſciſſæ, or parts of the poop.	Ordinates, or half Breadths.	Abſciſſæ, or parts of the poop.	Ordinates, or half Breadths.	Abſciſſæ, or parts of the poop.	Ordinates, or half Breadths	Abſciſſæ, or parts of the poop.	Ordinates, or half Breadths.
0	260	315	485	1538	996	4487	1831
2	262	382	521	1709	1054	4832	1914
9	271	456	559	1893	1114	5188	1998
21	283	539	600	2089	1177	5564	2084
37	299	630	642	2301	1242	5964	2174
59	317	729	686	2525	1309	6381	2265
86	339	838	732	2762	1378	6811	2358
119	364	957	781	3013	1449	7265	2454
159	390	1086	831	3278	1522	7738	2551
204	420	1225	884	3556	1596	8234	2652
256	451	1375	939	3849	1672	8750	2754
				4158	1750		

TABLE VII. *Of the Dimenſions of the Bow of greateſt Movement.*

Abſciſſæ, or length of the axis on the bow	Ordinates, or the depth of the Bow.	Impulſions.	Abſciſſæ, or length of the axis on the bow	Ordinates, or the depth of the bow.	Impulſions.
0	0	0	259	508	397
1	50	50	284	524	402
5	98	97	307	538	406
18	185	182	328	550	409
35	252	245	349	561	411
50	297	285	365	570	413
61	320	304	381	578	414
63	325	308	412	592	417
69	335	316	437	602	418
83	352	327	457	610	419
102	375	340	486	620	420
126	400	354	511	628	421
152	425	365	541	636	422
179	448	375	586	645	422
206	470	385	612	649	422
233	490	391	628	650	422

Our author remarks on Table I, that in joining two ſurfaces, A B R S, (*Fig.* 17) the bow may be formed nearly to what the figure repreſents, and will meet with the leaſt poſſible reſiſtance, in paſſing thro' the water, in a direct courſe, or in any oblique courſes which do not exceed 45 degrees. This bow has that particular property, that it will meet with the leaſt poſſible reſiſtance, without regarding how deep it ſinks into the water. It is not the curves of the ridges, A I S, and B H R, B H R; of which we give the abſciſſa and ordinates; it is of that which reſults from the ſection of the ſurface A B R S, cut vertically and perpendicularly to its length; the point A being the origin of the abſciſſæ extending along D C.

On Table II. He ſays, we muſt take the value of each abſciſſa from a ſcale of equal parts, and lay it off from A to X, or to C, on the ſtrait line A C, *Fig.* 18, beginning always at the point A; and then make the perpendiculars X V and C D equal to the correſponding ordinates in the table.

We ſhall now give our readers the ſubſtance of his Concluſion.

After having, to the utmoſt of my power, ſays our author, executed every part of the engagement I undertook, it will be proper now to recapitulate the principal things I have explained, eſpecially ſuch as relate to the figure of the ſhip; and I ſhall make no ſcruple again to affirm, that, I believe, I have given infallible rules to the builders, to determine their choice of the different plans that may be preſented to them of the ſame ſhip, We have, in the ſecond book, explained all that concerns a ſhip while a-float or at reſt: We may know if the whole weight be proportional to the ſolidity of the immerged part; if ſhe has ſtability or force to carry ſail; or if ſhe carries her guns high enough out of the water: And, in the third book, we have given proper rules to aſſure us ſhe will ſail well; drive but little, when cloſe hauled upon a wind, and readily anſwer all the motions of the helm. All the other qualities are ſubmitted to the proof of a calculation, which coſts but little labour: Even ſuch accidents as ſeem to depend on very irregular cauſes are conſidered; ſuch as the duration of the vibrations occaſioned by rowling, and thoſe of pitching; we may judge of them by examining the diſtribution of the weights, and in what manner every particular weight is ſupported in every different circumſtance.

Geometricians think no labour too hard, and do not ſatiſfy themſelves with what knowledge they have acquired, but are continually puſhing their reſearches to the higheſt pitch; notwithſtanding all this, we muſt ſometimes have recourſe to experiments on ſhips already built, which may ſerve as a term of compariſon. By theſe experiments we may, in an inſtant, diſcover things which could not be done any other way, without a great deal of labour; and, in forming another ſhip, it may ſuffice to take notice of their different dimenſions, and the neceſſary cauſes that may occaſion ſome alterations.

We have endeavoured, out of an infinite number of forms, to pick out the beſt; and where the diſpoſition of different parts contribute to carry a certain property to a higher degree, we have ſearched the moſt advantageous combination, to determine the *maximum*. We may, with certainty, make which property we pleaſe predominate, and at the ſame time know how far we may carry the others.

We have ſhewn, that the extreme breadth ſhould be five twelfths of the length, from the fore part, which is the poſition beſt ſuited to make the ſhip anſwer the motions of the helm; but it muſt be carried a little further forward, to make her ſteer well by the aſſiſtance of the ſails, though, by this means, the bow will become fuller, to the prejudice of her ſailing, and of that property which ſhould make a ſhip leſs ſubject of driving to the leeward. It will be impoſſible to reconcile theſe four properties; and, that we may not loſe too much of any one of them, we muſt reſolve to loſe a part of the others; and the ſureſt way, in moſt caſes, will be to embrace that which moſt favours the action of the rudder.

We have, in the firſt book, explained ſeveral methods of deſcribing the midſhip frame, which may be improved by the remarks in the ſecond and third books.

Suppoſe we cannot perſuade ourſelves to abandon the common practical rules, nor venture at once to go to the utmoſt point of perfection, yet it is to be wiſhed, that the breadth and depth ſhould bear but a very ſmall proportion to the length; it is a matter of great importance, and merits the utmoſt attention of the builders. The ſection of the midſhip frame ſhould be a triangle in light frigates, but a rectangle in ſhips built for burthen. In theſe laſt, the breadth is continued the ſame as in midſhips, for a conſiderable ſpace, nearly the fifth part of the whole length. The common rules are very well adapted to the building of ſuch ſhips, and want very little amendment, but are very deficient in the frigates, which begin to narrow, both fore and aft, from the very midſhip frame. The ſhips of war, as it were, keep a mean betwixt theſe two; they are ſhips of burthen, but their great weight is ſituated in a very inconvenient manner, their center of gravity being too near their metacenter; they muſt, on that account, and on account of carrying their metal, be broader in proportion than other ſhips.

The principal dimenſions being eſtabliſhed, we may form the ribbands, and ſo the work will be compleated. We may uſe the method of approximation, delivered in the XIth chapter of the firſt ſection of the firſt book; or conform to the tables, which we have with great pains calculated, and inſerted at the end of the laſt ſection, that the practical part may receive all the benefit that may accrue to it from theory.

So far M. *Bouguer*; and here follows what M. *Duhamel* has ſaid on the center of gravity.

Abridg-

Abridgement of what M. DUHAMEL *has said in his second Edition on the Center of Gravity.*

M. DUHAMEL in this edition, has given us an additional Chapter, wherein he explains a method to find, whether or no a ſhip will carry ſail.

The principle on which he fixes the ſtability or ſtiffneſs of a ſhip is the proper fixing the center of gravity of the whole body, including, as well, the maſts, yards, guns, *&c.* that are above the water, as the ammunition, ballaſt, *&c.* that are below the water; and in order to give us a diſtinct idea of that term, the center of gravity, he proceeds in the following manner:

It is eaſy to conceive that the ſame quantity of any matter may be put in different forms, but it will ſtill be the ſame weight; for a piece of lead in form of a globe of one inch diameter, may be extended ſo as to cover a circle of one foot or more diameter; but it is plain the lead will be the ſame weight in both forms, and if it were poſſible to preſs it ſo as to become a globe of one eighth of an inch diameter or leſs, this ſmall globe would weigh as much as the other great one; but becauſe the parts of matter cannot penetrate into one another, this cannot be effected. Let us then ſuppoſe the whole weight of the globe A (*Fig.* 20.) to be united into one point *a*, and we ſhall have an idea of what in mechanicks is called the center of gravity.

The center of gravity then, of any body, is that point, whether it be within or without that body by which if it was ſuſpended, or upon which, if it were ſupported, it would reſt immoveable in any ſituation, as if the weight of the whole body were united in that ſingle point. Hence, to find the center of gravity of any body, is to find that point, upon which, if the body reſted, all the other parts would be in an equilibrium. It will be neceſſary, firſt, to ſay ſomething of the equilibrium; for then we ſhall eaſily explain what is to be ſaid on the center of gravity.

In treating of the equilibrium, I ſhall explain the balance, becauſe the uſe and conſtruction of the balance, and of the equilibrium, are founded on the ſame laws.

The balance (*Fig.* 21.) conſiſts of a beam A B, and a fulcrum or point of ſupport C, the center on which the beam moves, and if this be the center on which the beam rests in equilibrio, it is the center of gravity of the beam; but as this point may be considered as one of those that form a line, it may be considered as the axis of the equilibrium; that is to say, as if formed by a line passing thro' the center of gravity: If we imagine a plane crossing the beam in the point C, we shall then have an idea of the plane of the equilibrium; that is to say, of a plane in which the center of gravity is to be found.

In order to make the beam of a balance true, the arms C A and C B, must be exactly of the same length, and likewise the weight of one arm must be equal to that of the other, and the fulcrum must be applied to the center of gravity.

Let us first consider the line A B, abstracted from breadth and thickness, and, supposing all its points to be homogeneous, they will all have an equal tendency to the center of the earth; and if there be as many points betwixt C and A as there are betwixt C and B, the line will rest in equilibrio on the point C, which will point out the center of gravity for the point S on the arm A C; and the point S, on the arm B C, being equally distant from the point C, and having an equal tendency towards the center of the earth, reciprocally destroys the weight of each other; and there being, by supposition, the same number of elementary points, betwixt A and C, as betwixt B and C, each will destroy the force of its opposite, and the line will rest in equilibrio, because the line is supposed to have neither breadth nor thickness, the point C, will be in the center of gravity; but if the fulcrum be moved towards A, or towards B, it is plain the equilibrium will be broke, because there being more elementary points on the one side than on the other, there will be a preponderating force, which will cause the line to incline; so we may perceive that the center of gravity of a line, or of a rod, every where of equal thickness and breadth, and all its parts of equal weight, will be exactly in the middle of the line or rod.

It will not be amiss here to remark, that in finding the centers of gravity of lines, or surfaces, we need only consider their extent, because as the matter of which they are formed is supposed homogeneous, all the parts will be equally affected with that tendency they have towards the earth's center, or that force which make bodies descend, affects all the parts equally.

It is easy to prove that the center of a parallelogram (*Fig.* 22.) is in N, the center of the figure; for, supposing the parallelogram to be formed by elementary lines parallel to A B, as we have already proved, that the center of gravity of a line is in the middle of it, if the line I K be drawn

drawn thro' the centers of gravity, of the elementary lines parallel to A B, it will be the axis of the equilibrium in which the center of gravity, of the figure muſt certainly be found. Let us then ſuppoſe other elementary lines parallel to B D; we ſhall have L M another axis of the equilibrium, in which likewiſe the center of gravity muſt be; and becauſe the point N is the only one, common to both axes, it muſt be the center of gravity; hence, the center of gravity of a parallelogram muſt be in the center of the figure; and for the ſame reaſon the centers of gravity of circles, ellipſes, of polygons, of any even number of ſides, will be in the centers of the figure, as is evident by a bare inſpection of the figures.

It will be as eaſy to find the center of gravity of any triangle (*Fig.* 23.) for, ſuppoſing it formed by the elementary lines A B, we have C D, one axis of the equilibrium; again, ſuppoſing it formed by the elementary lines E F, we have G H, the other axis of the equilibrium, ſo ſhall N, the point of their interſection, be the center of gravity of the triangle; hence, the center of gravity of any triangle will be in the point of interſection of two lines biſecting any two ſides, and drawn from the angles oppoſite to thoſe ſides. If we ſuppoſe a regular pentagon, (*Fig.* 24.) formed by elementary lines A B, we ſhall have the axis D C; again, ſuppoſing it formed by the elementary lines E F, we ſhall have the other axis G H, ſo ſhall N, their point of interſection, be the center of gravity of the pentagon.

As by ſuppoſing all ſurfaces to be formed by lines, we have diſcovered an eaſy method to find the centers of gravity of regular ſurfaces, ſo if we conſider ſurfaces, as the elements of ſolids, we may as eaſily find the centers of gravity of ſolids; for if we conceive the parallelopiped, (*Fig.* 25.) to be formed by an infinite number of parallelograms, parallel to *a b*, the centers of gravity of all the parallelograms will be in the center of the figures as was before proved; and if we draw a line *c d*, thro' all the centers of gravity, we ſhall have the axis of the equilibrium, in which the center of gravity of the parallelopiped is to be found, and as all the parallelograms are equal, we may conclude that the center of gravity of the parallelopiped is in the middle of the axis *c d*; and, for the ſame reaſon, the centers of gravity of a cylinder, of a ſphere, or of an ellipſoid, are exactly in the center of theſe ſolids.

As any priſm may be conſidered as compoſed of ſurfaces, or thin ſlices equal and ſimilar to their baſes, and that a ſtrait line drawn from the center of gravity of one baſe to that of its oppoſite, paſſes thro' all the

elementary

elementary ſlices, the center of gravity of all priſms, or cylinders, will be in the middle of that line which is the axis of the equilibrium.

As to the center of gravity of a triangular pyramid, it is plain it muſt be in a ſtrait line, drawn from the vertex to the center of gravity of the baſe; for, let the pyramid be divided into elementary ſlices, parallel to the baſe, the centers of gravity of all theſe ſurfaces will be ſimilarly placed, and, uſing the ſame operation on all the ſides of the pyramid, we ſhall have different axes of the equilibrium; their point of interſection, which will be one fourth of the length from the baſe, will be the center of gravity, and as a cone may be conſidered as a priſm of an infinite number of ſides, its center of gravity will likewiſe be in the one fourth of its axis from the baſe.

Hitherto we have conſidered ſurfaces and ſolids as compoſed of parts which are of equal weight; but if the parts are of unequal weights, the ſolutions will be falſe; for, ſuppoſing the part C B, (*Fig.* 26.) of the line A B to be gold, and the part C A to be iron, and the ſpecifick gravity of C B 3, and that of C A 1; the fulcrum being in the middle of the line, the part C B will raiſe the part C A. In this caſe, in order to find the fulcrum, on which it will reſt in equilibrium, we need only find the center of gravity of C B; which will be in *d*, the middle of that line, that part being ſuppoſed homogeneous, and, for the ſame reaſon, the center of gravity of C A, will be in *e*, the middle of the line C A. Let us now conſider the whole weight of the line C B, united in *d*, and the whole weight of the line C A, united in the point *e*; all that remains to be done, is to find the center of gravity of two bodies (*Fig.* 27.) the weight of *d* being 3, and that of *e* 1 pound. In order to ſolve this problem, let the two bodies be joined by a rod that will not bend, and as the two bodies together weigh 4, divide the rod *d e* into four equal parts, ſo ſhall the center of gravity C, be in the third diviſion from E, (*Fig.* 28); for the weight *d*, multiplied by the arm B C, will be equal to the weight *e*, multiplied by the arm A C. The arm of the lever A C, is to the arm B C as *d* to *e*; we ſhall explain this by an example taken from the common balance. Let A B (*Fig.* 29.) repreſent the beam of a good balance, four feet long, C the fulcrum; now as A C and B C are exactly the ſame length, that is, two feet each, and of equal weight; the beam will reſt in equilibrium on the fulcrum C: If we ſuſpend to the extremities of the beam, the weights D and E of one pound each, the beam will ſtill continue in equilibrium, becauſe the weight D of one pound is to the lever C B of two feet, as the weight E of 1 pound is to the arm C A of 2 feet: But ſuppoſe E 2 pound, and D 1, and placed as before, it is it is plain, the beam A B will incline to the side on which D is placed, because the weights are not reciprocally proportional to their distances from the fulcrum; and, in order to regain the equilibrium, we must shorten the arm of the beam C B, in the same proportion the weight E is augmented; so placing the weight E *(Fig. 30.)* at the point F, the two weights will then be in equilibrio; for now the weights will be reciprocally proportional to the lengths of the arms of the lever. Since D = 1 lb × A C = 2 feet; E 2 lb × C F = 1 foot = 2; which may be proved by experiment.

This may be demonstrated after another manner; for, supposing the weights suspended to the extremity of the beam, if they be equal, as in *Fig.* 31, the fulcrum must be at the point C, the middle of the beam; but if E be double the weight of D, then must the fulcrum be in the point F, two thirds of the beam from the end A; and then D : B F : : E : A F. Supposing then P, (*Fig.* 32.) to be 4 pounds, and R 12 pounds, and one suspended to each arm of the beam; in order to find the fulcrum, say, as 16, the sum of both the weights, is to 12, the greatest weight, so is M N, 8 feet, the length of the whole beam, to M F 6 feet, the distance of the fulcrum from M. Then P : F N : : R : F M.

Hence we discover a remarkable property in the lever; for in moving the fulcrum from C to F, (*Fig.* 31.) neither the absolute weight of the mass D, nor that of the arm of the lever A F, is augmented, since the beam is supposed to have no weight: And, to try this by an experiment, let there be as much weight added to B, as will occasion the beam to be in equilibrio on the point F, before we put on the weights E and D; nevertheless, the small weight will resist the action of the great one. So the relative force of D, in respect of E, is augmented in varying the velocity; for if we put the lever in motion on the fulcrum F, we shall perceive that in the time B describes an arch, suppose of 1 foot, A will describe an arch of 3 feet: Hence we may say, with *Des Cartes*, that it will take as much force to move ten pounds with 20 degrees of velocity, as to move twenty pounds weight with 10 degrees of velocity.

Let us endeavour to make this still plainer. If the two bodies, A and B, are of different weights, their center of gravity (or the fulcrum on which the rod E D, that joins them, will rest immoveable) will not be in the middle of the line; this will appear very plain, only by observing what will happen to the beam, when there is more weight in one scale than in the other.

In order then to find the fulcrum F, on which the beam shall rest in equilibrio, let us suppose it already found, and that E is double the

weight

weight of D; it is evident, that E cannot have the leaſt motion, without giving D a motion at the ſame time; and the two bodies will continue in equilibrio till both are put in motion.

It is not then neceſſary, that the two bodies be of equal weight to preſerve the equilibrium; but it will be neceſſary, that D have the ſame difficulty in moving that E has; and, becauſe E is ſuppoſed double the weight of D, it muſt take double the purchaſe to move it: Hence it follows, that the ſame force which will make E run over one degree, will, in the ſame ſpace of time, make D run over two degrees, provided E be double the weight of D; but if triple the weight, it will run over three degrees, and *c* as *m*, (*Fig.* 31.) for the effect is always proportioned to the cauſe. Hence this natural conſequence; if the motion of D be double or triple that of E, its relative weight will be double or triple its real; and if the motion of D be triple that of E, the equilibrium will be preſerved, although D be only one third of the weight of E. Now, if it be obſerved, that the fulcrum F, is three times the diſtance from A that it is from B, and that the arches of circles are in proportion to their radii; the arch, deſcribed by the point A, with the radius F A, will be thrice the arch deſcribed, by the point B, with the radius F B, in the ſame ſpace of time, juſt as the weight of E is triple that of D. Hence, to keep two bodies in equilibrio, their diſtances from their common center of gravity muſt be reciprocally proportional to their weights. D : E : : F B : F A.

We have made this digreſſion, to ſhew the difference betwixt the abſolute and relative force of any body, which will aſſiſt us to underſtand the nature of *momenta*, which ſhall be treated of hereafter: We ſhall here ſhew how to find the centers of gravity of a ſyſtem of bodies of different weights, ſuppoſing them joined by an inflexible rod, paſſing through all the centers of gravity, the rod being conceived without any weight.

Let us then ſuppoſe the inflexible rod A B (*Fig.* 33.) paſſing through the centers of gravity of the ſeveral bodies *a*, *b*, *c*, *d*, *e*, *f*, whoſe abſolute weights are different; firſt find the center of gravity of two, as of *a* and *b*, which will be in *g*, if we make *g a* (the diſtance of *a* from the center of gravity) to *g b* (the diſtance of *b* from the center of gravity) as the weight of *b* is to that of *a*: Then conſidering *a b* as united in *g*, let us find the center of gravity of *g* and *c*, which ſuppoſe in *h*, and then conſider the weights *a*, *b*, and *c*, as united in *h*; and then uſing the ſame proceſs, on the other ſide, we ſhall find the center of gravity of *e* and *f* in the point *i*; and conſidering *e* and *f* as united in *i*, we may find

find the center of gravity of *e* and *d*, which ſuppoſe in *l*. Now, the ſum of the weights *a*, *b*, and *c*, being united in *k*, and the ſum of the weights *e* and *f* united in *l*, we need only find the center of gravity of *b* and *l*, which will be the center of gravity of the whole ſyſtem, compoſed of the bodies *a*, *b*, *c*, *d*, *e*, *f*; and if the center of gravity be at *m*, there muſt be the fulcrum, on which the whole ſyſtem will reſt in equilibrio; juſt as if *a*, *b*, and *c*, were put into one ſcale, ſuſpended on the point *b*, and *d*, *e*, and *f*, put into another ſcale, ſuſpended by the point *l*, they would be in equilibrio, provided *m* were the fulcrum on which the beam reſts; becauſe *b m* is to *l m*, as *d*, *e*, *f*, placed in *l*, is to *a*, *b*, *c*, placed in *b*.

It is very plain, that if the bodies *a*, *b*, *c*, and *d*, *e*, *f*, (*Fig*. 34.) were placed in the ſame plane, on different ſides of the axis of the equilibrium A B, they would remain in equilibrio upon that axis, provided their ſeveral weights be the ſame as in the preceding: The diſtance of each body from the axis A B, will be equal to the diſtance of each body from the center of gravity *m* (*Fig*. 33.), that is, A *a*, *b* M, *c* N, (*Fig*. 34.) equal to *a m*, *b m*, *c m*, (*Fig*. 35.) and P B, *e* P, and *d* O, equal to *f m*, *e m*, and *d m*.

It is likewiſe plain, that if in a ſyſtem of bodies on the line A B, (*Fig*. 33.) their center of gravity *m* be in one of the bodies, it may be reckoned as a cypher, in regard to the center of gravity of the whole ſyſtem; though its particular weight adds to the weight of the whole ſyſtem.

Though my intention here is to confine myſelf to treat of the center of gravity, ſo far as is neceſſary to give my readers a clear underſtanding of the method of finding it in ſhips, yet I cannot allow myſelf to omit ſhewing how to find the center of gravity, of any number of bodies placed at random in the ſame plane; ſuppoſe *a*, *b*, *c*, *d*. (*Fig*. 35.)

The center of gravity of each particular body, (ſuppoſed to be known;) we muſt firſt find the center of gravity of *a* and *b*, joined by an inflexible rod, by the foregoing method, which ſuppoſe in *e*; and then conſidering *a* and *b* as united in *e*, find the center of gravity of *e* and *d*, ſuppoſe in *f*; laſtly, conſidering *a*, *b*, and *d*, as united in *f*, we need only find the center of gravity of *f* and *c*, which ſuppoſe in *g*, ſo ſhall *g* be the center of gravity of the whole ſyſtem. I ſhall conclude this ſubject, with ſome remarks on what has been ſaid.

I. The center of gravity of any ſyſtem of bodies, may be found without knowing the dimenſions of their bulk, if their weights be known; for ſuppoſing *a* and *b* to be of different matter, (*Fig*. 36.) the one of ſtone, and the other of wood, and each to weigh one pound, their center of gravity will be in *e*, the middle of the beam *a b*.

II. If the bodies be homogeneous, and of the ſame ſpecifick gravity, their centers of gravity may be found by their bulks, without knowing their weights; for, let the two bodies *a* and *b*, (*Fig.* 37.) be homogeneous, and let *b* be double the bulk of *a*, then will their center of gravity be in *e*, two thirds of the length of the beam *d e*; and this is found without having any regard to their weight, for *d c* being double *c e*; then $a : b :: c e : c d$.

III. As the center of gravity of any ſyſtem of bodies, conſidered, abſtracted from any weight, may be found by their bulks; it is in this ſenſe, that the centers of gravity of lines, ſurfaces, or of any ſpace whoſe weight is not conſidered, are ſaid to be found.

IV. We may likewiſe perceive that the center of gravity of any ſurface, limited by ſtrait lines, may be found by reducing them to parallelograms, triangles, or any other regular figures, whoſe centers of gravity may be found by the preceding rules; we may then ſuppoſe an inflexible rod paſſing thro' theſe centers of gravity, and the center of gravity of the ſyſtem *a*, *b*, *c*, it may be found as in (*Fig.* 35).

It will be the ſame with reſpect of ſolids; for every ſolid may be divided into parallelopipeds, priſms, cones, or triangular pyramids, and by forming another ſyſtem by the centers of gravity of the ſeveral bodies, we may find the center of gravity of the whole ſyſtem by the rules already delivered.

We may now perceive how the center of gravity of a ſhip may be found; for as the two ſides A and B, (*Fig.* 38.) are equal and ſimilar, it follows that the center of gravity muſt be in a plane erected perpendicular to the keel, which will be in the plane of the equilibrium of the ſhip, and tho' ſhip's bodies are very irregular figures, they may be reduced, nearly, to regular ones, by dividing them into ſeveral ſmall parts, and the center of gravity of each may be found as before; but as this method would be too tedious for practice. I ſhall therefore attempt to ſhew how it may be performed by M. *Bouguer*'s method of *momenta*.

The *momentum* of any heavy body, or of any extent conſidered as a heavy body, is the product of that weight, or of that extent multiplied by the diſtance of its center of gravity from a certain point aſſumed at pleaſure, which is called the center of the *momentum*, or from a line which is called the axis of the *momentum*.

In order to comprehend this, it muſt be remembered that we made a diſtinction betwixt the relative and abſolute weight of any body; the relative

relative weight of any body considered with respect to that of any other body, or, with respect to a point, is augmented or diminished in proportion to the distance of that body, from the fulcrum, the absolute weight remaining still unvariable; or it is the relative weight which mathematicians consider, when they use the *momenta*, by multiplying the weight, or extent of any body, by the distance of its center of gravity from a point or line assumed at pleasure.

Example. Let B, (*Fig.* 39) be 6 pounds, A the center of the *momentum* of B; and let A B be 4, then shall 24 be the *momentum* of B, relative to A. Again, let B be 6 pounds, (*Fig.* 40.) A B 4, as before; 24 will still be the *momentum*; let C likewise be 6 pounds, and A C 3, so its *momentum* will be 18, and the *momentum* of the two bodies will be 42.

If the two bodies in the same plane are not in the same direction, from the point A, that will make no alteration, if we consider them relatively to an axis A A 4, its *momentum* will be 24, and the distance of C being 3, from the axis A A, and weight 6 pounds, its *momentum* will be 18, so shall the *momentum* of the two be 42 as before. I said the center, or axis of the *momentum* may be placed at pleasure; so it may be placed betwixt two bodies; if then it may be at the point A, (*Fig.* 42.) precisely betwixt the two bodies B and C, suppose 6 pounds each, the *momenta*, of each being 12, they will be equal, and the center of the *momentum* will be in the center of gravity of the two bodies; but if we place the center of the *momentum* in D, the *momentum* of C being $6 \times 3 = 18$, and that of B $6 \times 1 = 6$, the equilibrium will be destroyed.

We may now begin to perceive the relation betwixt the center of gravity and the center of the *momenta*, but to make this still plainer, we shall shew that the sum of the *momenta* of all the bodies that compose a system is equal to the *momentum* of all the bodies considered as united in their common center of gravity.

If we multiply all the weights 6, 5, 8, 4, 10, &c. which are placed along the beam A B, (*Fig.* 43.) by the distance of the center of gravity of each, from the point A, which is assumed as the center of their *momenta*; that is, $6 \times 1 + 5 \times 2 + 8 \times 3$, &c. and, lastly, 6×11 the the sum of all these products, will be 396; on the other hand, if we add the weights of all these bodies into one sum, that is, $6 + 5 + 8 + 4$, &c. + 6, the whole will be 66; and this multiplied by 6, the distance of the point C, the center of gravity of the system from A, the center of their *momenta*, we shall have 396 for the *momentum* of the sum of all the weights as united in C, the center of gravity of the whole system, equal to the sum of all the *momenta* of the bodies taken seperately; and that it will always be ſo is evident, for, ſince the point C is the center of gravity of the whole ſyſtem, in which all the weights are ſuppoſed to be united, and the point itſelf ſo placed, in reſpect of A, that all the weights placed betwixt C and B gain as much energy or force, by their diſtance from the point A, as the weights, placed betwixt C and A, looſe of their particular relative force.

Hence, the *momentum* of the center of gravity, of a ſyſtem of heavy bodies, is equal to the ſum of the *momenta* of the ſeveral particular bodies that form the ſyſtem; but it will be proper to remark, that if we conſider the *momenta* of a ſyſtem, with reſpect to a point A, which happens to be in the center of gravity of one of the extreme bodies, (*Fig.* 44.) it will make no alteration in the operation, only omitting that body which may be deemed a cypher; for, ſuppoſing the body A 6 pounds, then $5 \times 1 + 8 \times 2 + 4 \times 3 + 41 \times 5 + 9 \times 6 = 292$, and $6 + 5 + 8 + 4 + 41 + 9 = 73$, which, muliplied by 4, the diſtance of the center of gravity of the ſyſtem from A, the product will be 292, equal to the former.

Let the bodies be the ſame weight, and placed as before, and D, the center of the *momenta* (*Fig.* 45.), be betwixt two of the bodies, the ſum of the weights, 8, 4, 41, 9, 6, 5, multiplied by their diſtance from D, which is ſuppoſed the center of the *momenta*, will be equal to the ſum of all the weights 6, 5, 8, 4, 41, 9, multiplied by the diſtance of their center of gravity C, from D, the center of their *momenta*; obſerving to ſubtract the product of the weights of thoſe on one ſide of the point D, from thoſe on the other ſide, becauſe each endeavouring to turn the beam to its own ſide, they will have contrary effects.

Suppoſing D to be exactly in the middle betwixt 5 and 8; we have $8 \times 5 = 4 + 4 \times 1.5 = 6 + 41 \times 3.5 = 143.5 + 9 \times 4.5 = 40.5$, the ſum of the whole is 194; and on the other ſide $5 \times .5 = 2.5 + 6 \times 1.5 = 9$, their ſum 11.5 ſubtracted from 194 remains 182.5, exactly equal to the ſum of all the weights $8 + 4 + 41 + 9 + 5 + 6 = 73$, which, multiplied by 2.5, the diſtance of their center of gravity C, from D, the center of their *momenta*, is 182.5; but it muſt be obſerved, in this laſt, we take the ſum of all the weights, without ſubracting thoſe on the one ſide from thoſe on the other, becauſe they all tend towards the center of the earth; whereas, in finding the *momentum* of each particular body, they being ſuſpended on different ſides, their effects will be in a reciprocal proportion to their diſtances.

Laſtly, ſuppoſe the center of the *momenta* be in E, (*Fig.* 46.) it is plain E equal 8 can have no *momentum*, becauſe its diſtance from the center

center is 0; $E \times 0 = 0$, and then multiplying 4, 41, 9, by their respective distances from E, and, from the sum of their product, subtracting the product of the sum of 5 and 6, multiplied by their respective distances from E; subtracting, I say, this product from the sum of the other products, the remainder will be equal to the sum of all the weights, multiplied by the distance of their common center of gravity C, from E, the center of the *momenta*. Having thus proved that the sum of all the particular *momenta* that compose a system are equal to the product of the sum of all the weights, multiplied by the distance of their center of gravity, from the center of the *momenta*, it will thence follow, that, if the sum of all the *momenta* be divided by the sum of all the weights, the quotient will give the distance of the center of gravity from the center of the *momenta*; or, which is the same thing, if the *momenta* of several bodies, in respect of a point or line, be divided by the weight of these bodies, the quotient will be the distance of their center of gravity from that point or line which was assumed for the center of their *momenta*.

As for example, if it were required to find the distance of C, the center of gravity of the system, (*Fig.* 47.) from A the center of the *momenta*; the sum of the *momenta* is 292, this divided by 73, the sum of the weights, the quotient 4 is the distance from A to C.

As examples taken from things of common use are most instructive, I shall shew that the construction of the steel-yards is founded on the same principles; but let it be observed, that we have no regard to the weight of the beam A B, (*Fig.* 48.) or we suppose that the part A C, of the beam is in equilibrium with the part B C, C being supposed the fulcrum on which the beam rests; we likewise suppose the distances A C, C *e*, *e f*, *f g*, *h i*, *i k*, *k l*, *l m*, to be equal; and that the weight *e*, is one pound.

Is is plain, if we put the weight *e* in E, we must put one pound in D, to gain the equilibrium; but if *e* be put in *f*, we must put 2 pounds in D, because the *momentum* of *e* placed in *f*, is 2; and for the same reason, if *e* be put in *g*, we must put 3 pounds in D; if in *h*, 4 pounds; if in *i*, 5 pounds; if in *k*, 6; if in *l*, 7 pounds; and, if in *m*, 8 pounds; for *e* equal 1 pound multiplied by *m l*, equal 8, is equal to D 8 pounds multiplied by A C equal 1.

Supposing the points E, *f*, *g*, *h*, *i*, *k*, *l*, and *m*, had a weight of one pound suspended to each, these weights being all equal, and equally distant from one another; and supposing C, the center of their *momentum*, we shall have their sum by taking E once, *f* twice, &c. and *m* eight times,

times, their ſum will be 36, which, divided by 8, the quotient 4.5, gives, the center of gravity of the ſyſtem C B.

Now we have got an eaſy method of finding the center of gravity of a ſyſtem of heavy bodies. Thus, ſince the centers of gravity of a ſyſtem of heavy bodies, or of ſurfaces, or of ſolids, will be in the ſame place, and when we know the abſolute weight, or the extent of each of theſe bodies or ſurfaces, and the diſtance of each center of gravity from a certain point, aſſumed for the center of the *momentum*, or from a line, which is ſuppoſed the axis of the equilibrium, we may always find the diſtance of the center of gravity from that point which we have choſe for the center of the *momenta*, or from that line which we regard as their axis. It is from theſe principles that M. *Bouguer* has furniſhed the builders with an eaſy method of finding the center of gravity of ſhipping.

It now remains to apply theſe principles, which we have eſtabliſhed, to the finding of the center of gravity of a ſhip, and to begin with the ſimpleſt operations, we only propoſe at firſt to find the center of gravity of the area of a ſection of a ſhip taken at the load water line, which is repreſented in (*Fig.* 49.) by A B.

I. The two ſides of a ſhip being equal and ſimilar, the line A B may be conſidered as the axis of the equilibrum, in which the center of gravity of that ſurface is to be found.

II. The curves that form the ſides of that ſurface, being very irregular, muſt be reduced as near as poſſible to regular ones, by dividing the ſurface, with the ordinates *a a*, *b b*, *c c*, *d d*, obſerving to place them at equal diſtances from one another, and likewiſe the diſtances muſt be ſo ſmall, that the portion of the curves intercepted betwixt them may be conſidered as ſtrait lines, which will be near enough for practice, as we do not here propoſe the utmoſt degree of exactneſs.

III. Theſe ordinates will divide the ſurface A, into a number of parallelograms, ſuch as *b d*, *d b*, which may be conſidered as ſuch, on account of their being ſo very ſmall, it is plain, the center of gravity of the parallelogram *b d*, *d b*, is at the point where the line *c c* interſects the line A B; and it will be ſo with all the reſt, ſo the centers of gravity of all the parallelograms will form a ſyſtem diſtributed on the line A B.

IV. To find the center of gravity of the ſyſtem, in reſpect of A, which is aſſumed for the firſt term of the *momenta*; we muſt, as was before obſerved, multiply the ſurface of each parallelogram by the diſtance of its center of gravity from the point A, and ſo, having the ſum of all the *momenta*, we may divide that ſum, by the ſum of the ſurfaces of all the parallelograms, or by the whole ſurface A B, and the quotient will be the

the diſtance of the center of gravity from the point A, the axis of the *momenta*.

M. *Bouguer* has abbreviated this operation; for, conſidering that we muſt have the area of the whole ſurface A B, before we can obtain a ſolution, he finds that by the method delivered in Chap. VIII. of the Appendix, which is as follows:

1ſt. Divide the whole length in ſeveral equal parts *a a*, *b b*, *c c*, *d d*, &c.

2d. Meaſure all the ordinates *a a*, *b b*, *c c*, *d d*, &c. and add them altogether except the firſt and the laſt, of which we muſt only take one half of each.

3d. Multiply that ſum by the diſtance betwixt the ordinates, and the product will be the area of the ſection A B.

The ſecond thing to be had is the ſum of the *momenta* of all the elementary parts of the ſurface, which M. *Bouguer* has readily done, by multiplying each ordinate into its diſtance, from the point A; then he takes the ſum of all theſe products, except the firſt and laſt, of which he takes only one half of each; and by multiplying that ſum by the diſtance betwixt the ordinates, he has the ſum of all the *momenta* of the elementary parts of the ſurface, which he divides by the area of the ſurface, before found; the quotient gives the diſtance of the center of gravity of the whole ſurface from the point A.

To explain this by an example, let it be required to find the center of gravity of a ſurface A B (*Fig.* 50.) 160 feet long, in order to which:

1ſt. Divide the ſurface by the ordinates *a b*, *c d*, *e f*, which are here 20 feet diſtant from one another.

2d. Omitting the line A, which here repreſents one of the tranſoms, becauſe we aſſume it for the axis of the *momenta*. It is 18 feet long.

Ordinates.	feet.	in.	lines.		Diſtant from A.	Product.
½A 18,	9					feet.
a b	23	0	0	×	1	23
c d	28	0	0	×	2	56
e f	30	0	0	×	3	90
g h	31	0	0	×	4	124
i k	30	0	0	×	5	150
l m	28	0	0	×	6	168
n o	21	0	0	×	7	147
½ B	0	6	0	×	8	4
Sum of all the Products						762
Diſtance betwixt the ordinates						20

f. in. lines.

Sum of the ordinates 200) 15240 (76 : 0 : 3½

Suppoſe

Suppose then we find the centers of gravity, of the surface of each section contained betwixt the load water line and the keel; by the same method, we shall then have a system of heavy bodies, which will have their centers of gravity in a plane erected perpendicular to the keel at their several distances from the line A B, which is assumed for the axis of the *momenta*. In order then to find the position of the center of gravity of the hull, in respect to the length, we must find the position of the center of gravity of the system, with respect to the line A B, which we assume for the axis of the *momenta*, or for the first term. (*Fig.* 51.)

Having by the preceding operations found the area of each water-line, and its center of gravity, we need only multiply the area of each section by the distance of its center of gravity from the line A B, and add all the products, except that of the first and last, of which we must only take one half of each, and then divide the sum of all the products, by the sum of all the areas, observing to take only half the first and last, and the quotient will give the distance of the center of gravity of the whole system from the line A B, the axis of the *momenta*; we shall explain this by the following example:

	Areas of surfaces.		Centers of gravity from A B.	Products.	
½ A	2000	×	76	76000	
C	1800	×	82	147600	
D	1000	×	90	90000	
E	3700	×	80	56000	
F	400	×	70	28000	
½ Keel	55	×	80	4400	
					f. in. lines.
	4955			) 402000 (	81 1 6

Having divided 402000, the sum of the *momenta*, by 4955, the sum of the surfaces, we have 81 feet 1½ inches, the distance of the center of gravity of the system from the vertical line A B, which will be nearly in the line H H.

It yet remains to find at what height above the keel in the line H H, the center of gravity of the hulk, or of the submerged part of the ship, will be found: In order to which, let us take G *g*, the upper side of the keel for the axis of the *momenta*, or the first term; then it is only finding the *momentum* of each surface with respect to the keel; (the distances betwixt each section being supposed 4 feet,) and then dividing the sum of all the products by 4955, the sum of all the surfaces.

Sur-

Surfaces.				
f f	400	×	1	400
e e	700	×	2	1400
d d	1000	×	3	3000
c c	1800	×	4	7200
a a	2000	×	$2\frac{1}{2}$	5000
				17000
Diſtance betwixt				4

f. in. lines.
4955) 68000 (13 8 2 is the diſtance of the center of gravity of the hull above the keel, which will interſect the line H H in the point I.

In the preceding calculations we have ſuppoſed the hulk to be compoſed of an homogeneous matter, all parts of which, in bulk, will be of equal weight; now, tho' this is a caſe that can never happen in a ſhip, which contains various things of different weights, yet it may not be altogether uſeleſs to the builders, ſince all ſhips of the ſame rate having the different weights placed nearly ſimilar to their lengths, they may find the center of gravity as above, and comparing it with the center of gravity of a ſhip, which is known by experience to have all the good qualities that can be expected, we may diſcover if the center of gravity of the ſhip we are to build be properly placed, and beſides it will aſſiſt us to underſtand what follows.

It would be a very complicated and laborious taſk to find the center of gravity of a ſhip properly maſted and rigged with all her proviſions and furniture on board, and, tho' I do not deſign to engage in the ſolution of that point, I think it would be unpardonable in me not to mention the action of a heavy body upon the fluid that ſupports it, and the re-action of the fluid on the floating body.

It was obſerved, in the beginning of this chapter, that the whole weight of any body may be conſidered as united in its center of gravity, and that if it were ſuſpended by a line faſtened to its center of gravity, that line would reſt in a vertical poſition, and its direction would paſs thro' the center of gravity, and the center of the earth; but a body which floats in a fluid is not ſupported by its center of gravity, but by the preſſure of the environing filaments of water, which being conſidered as infinitely ſmall, each will act upon an infinitely ſmall portion of the ſurface of the floating body, relative to the ſpecifick gravity, and, in proportion to the height of theſe filaments, conform to a principle applicable to all fluids; namely, that the weight of a column of any fluid will be in proportion

tion to the ſpecifick gravity of the fluid, and the height of the column multiplied by its baſe.

The preſſure of the fluid acting upon all the ſubmerged parts of the ſolid body, in the ſame manner that gravity acts upon all the parts of matter, the effect of ſuch preſſure will be united in a ſphere of wax, of the ſame ſpecifick gravity with the fluid, and which is intirely ſubmerged, preciſely to the ſame point as the center of gravity of the ſphere of wax; we muſt then conceive that the preſſure of the fluid acts immediately on the ſurface of the ſubmerged body; but its action is united in its center of gravity, juſt as if it exerted itſelf upon every part of the ſolid body. Wax is nearly the ſame weight with water, and if one ſinks a ſphere or ball of that matter, its preſſure on the fluid will be united preciſely in its center, or in the ſame point in which the whole weight of the ball does act; ſo in that ſuppoſition the center of the preſſure of the fluid coincides with the center of gravity, the action of each being united in the center of the ſphere.

But this is not all; for as heavy bodies, by their gravity, endeavour to approach the center of the earth, in a vertical line paſſing thro' their center of gravity, tending directly towards the center of the earth; ſo the preſſure of fluids endeavours to carry bodies in a vertical tending from the center of the earth towards their ſurface, and paſſing thro' the center of gravity of the ſubmerged part which forces them towards the ſurface; ſo in any ſubmerged body at reſt, theſe two oppoſite forces coincide in the ſame vertical, acting ina quite contrary direction to one another.

We muſt conceive then all heavy bodies endeavouring to approach the center of the earth, by a ſecret force inherent to all the parts of matter; ſo, (*Fig.* 52.) the globe of lead *b* tends towards the center of the earth in a vertical ſtretching from the point of ſuſpenſion *a*, thro' the center of gravity of *b*.

Thoſe bodies that weigh leſs than a column of water, (of the ſame bulk), in which they ſwim, endeavour to riſe by the preſſion of the fluid in a vertical line tending from the center of the earth to the center of gravity of the ſubmerged body; ſo the globe of cork *d* tends towards the ſurface in a vertical line ſtretched from the point *c*, to which it is faſtened to the center of gravity of the body *d*.

Let us then ſuppoſe two hooks *a* and *c* faſtened to the oppoſite baſes of the glaſs cylinder A, B, C, D, full of water, and let a ball of lead be ſuſpended by a hair to the hook *a*, and one of cork, faſtened by another hair to the hook *c*; it is plain, if the cylinder be upright, the ball of lead will deſcend towards *c*, with a force equal to its weight, leſſened

by

by the weight of the fluid it diſplaces, and the ball of cork will riſe with a force equal to the weight of water it diſplaces, leſſened by the weight of the cork, and if the hair that faſtens them be cut, they will be affected by contrary forces, *b* deſcending in the vertical *a c*, and *d* aſcending in the vertical *c a*, they will meet in the ſame point *e*, of the axis of the cylinder A B C D. But if we ſuppoſe the cylinder inclined as in (*Fig.* 53.) each body will take a different vertical, but parallel to one another; ſo that if both were let looſe, *b* would deſcend towards *f*, and *d* aſcend towards *g*, and never meet. Let us ſuppoſe them joined by a rod *b*, *e*, *d*, of the ſame weight with water; it is plain that each body will obey the force that acts upon it, *b* deſcribing the arch *b g*, and *d* deſcribing the arch *d b*, they will place themſelves in the ſame vertical, parallel to *a f*, or *c g*; and if the force which the preſſure of the water exerts on *d*, be greater than the force of gravity exerting on *b*; then will *d* draw *b* towards the ſurface of the water. On the contrary, if the force of gravity, acting upon *b*, be greater than the force of the preſſure of the water, acting on *d*, then will *b* draw it towards the bottom: But if the forces be equal, *b* and *d* will reſt in the middle of the fluid in the ſame vertical.

The two bodies will then turn round a point in the rod *b*, *e*, *d*; but it will not be eaſy to aſſign that particular place; it appears that if *b* endeavours to deſcend with a greater force than *d* to aſcend, in that caſe the center of rotation will be neareſt to *d*, and, on the contrary, if the force that raiſes *d* be greater than that which depreſſes *b*, it will be neareſt to *b*. Hence, in all heavy floating bodies which are at reſt, the center where the effect of the gravity of the body is united, and the center where the effect of the preſſion of the water is united, are in the ſame vertical, tho' ſeldom in the ſame point, as in a globe of wax which was ſuppoſed to be of the ſame ſpecifick gravity with water.

In order to apply theſe principles to ſhipping, let us examine what would happen to a ſtick, ſunk endways perpendicularly into the ſtanding water. Now this ſtick (*Fig.* 54.) being ſuppoſed all homogeneous, its center of gravity in air would be in *e*, the middle of the ſtick; let us ſuppoſe the ſtick ſo light that it ſinks perpendicularly only to *d*, the one fourth of the length *a b*: Now the ſtick being an homogeneous cylinder, the center, where the whole force of the column of water diſplaced is united, will be in *e*, the middle of the ſubmerged part.

Now, admitting all theſe ſuppoſitions, it is plain, when the ſtick is in a vertical poſition, the two oppoſite forces acting in the ſame vertical line will deſtroy each other, and the ſtick will reſt in that vertical poſition; but if the ſtick be but a little inclined as in (*Fig.* 55.) the caſe will be quite otherwife; for the gravity which refides in the point *c*, exerting itfelf in the direction *c g*, it will concur with the preffure of the water acting in the direction of the line *e f* to overturn the ftick, or place it horizontally on the furface of the water.

The center of gravity of the ftick will always be in the middle of it, at the point *c*, becaufe it never changes its pofition with refpect to the ftick (*Fig.* 56.) and the center of the preffure of the water will always be in the middle of the fubmerged part, or rather of that fpace which is abandoned by the mafs of water difplaced, which will be in the point *e*, in the fame vertical with the center of gravity of the ftick, and fo the whole will be at reft.

Let us alter fome of thefe fuppofitions, and we fhall find the fame caufes produce different effects.

Suppofe then (*Fig* 57.) the part *a c*, of the ftick *a b*, to be, if you pleafe, three times the weight of *c b*, of the fame ftick; the center of gravity of the ftick in air will then be towards *d*; the ftick being nearly of the fame weight with the column of water difplaced, will fink, fuppofe to *e*, the center of the impreffion of the water will be pretty near to *d*; but fuppofing it in *c*, or in any other point not below *d*, it is plain, when the ftick is inclined, as in *Fig.* 58, it will return to the vertical pofition; for the force of gravity which acts in the direction of the line *d g*, will draw the end *a* towards *i*, and will concur with the force that refults from the preffion of the water in the direction of the line *c f*, to bring the ftick into its vertical pofition.

To make this ftill plainer, let us incline the ftick a little more; we may eafily perceive, in *Fig.* 59, that if one purchafe be applied to *g*, acting in the direction of the line *g d*, and another purchafe applied to *f*, acting in the direction of the line *e f*, the extremity *b* would approach to *h*, and the extremity *a* to *i*, and the ftick would be in the vertical *h i*.

We may conclude, from this experiment, that any floating body will recover its vertical pofition, when the center of gravity is below the point where the force of the preffion of water is united. The ftability will be diminifhed, if the center of gravity be never fo little above the center of preffion; and the body will overturn, when the center of gravity is raifed to a certain height above the center of preffure; for, in this laft cafe, both act in concert to overturn the body; whereas, in the firft, both join to preferve its upright pofition.

It was before obferved, that the point fhifts, on which the points *c* and *d* are turned round. We fhall now remark, Firft, That this will be according as the force of *c* or *d* predominates. Second, According to the

the poſition of *c* and *d* upon the ſtick *a b*. Third, According to the difficulty that *a* will find in diſplacing the fluid, to bring itſelf to *i*, or that *b* will find in bringing itſelf to *h*; and it is poſſible, it may vary according to the different inclinations of the ſtick. If this point of rotation were invariable, and a method of finding it could be obtained, we might then, without regarding the preſſure of the water, know where to place the center of gravity, either to keep the ſtick upright or horizontal. I ſhall explain this by an experiment, which may be made by a well-known toy, or play-thing for children.

Every one has ſeen (*Fig.* 60.) the ſmall ivory puppet, which keeps itſelf in a vertical poſition, upon the point of a needle, by the aſſiſtance of two counter weights, *c* and *d*, which being joined together by a wire, are placed a good way below the pivot that ſupports the figure.

The weight of the figure is eſteemed as nothing, when compared with the weights *c* and *d*; ſo the center of gravity of *c* and *d* will be towards *m*. If the figure is inclined towards *i*, the weight *c* will be carried towards *e*, and the weight *d* towards *f*; ſo the center of gravity will ſhift towards *n*; and as it ſtrives to approach the center of the earth, and place itſelf in the vertical *m b*, the figure will recover its firſt ſituation. It is evident, that it will be quite otherwiſe, if the weights *c* and *d* are placed above the pivot, which ſupports the figure; for if they are placed in *i* and *k*, and the figure be inclined never ſo little, they will both act in concert to overturn the figure. We may likewiſe ſee, that if they are placed in *g* and *b*, at the extremities of the plane of the pivot, which is ſuppoſed to be their center of gravity, they will not, in the leaſt, contribute to keep the figure upright.

From this experiment we may infer, Firſt, In order to keep the figure upright, the two weights, *c* and *d*, muſt be exactly equal, or their difference adjuſted by their diſtance from the line *b m*, ſo that their center of gravity may be in that line *b m*. Second, It will be neceſſary, that the counter weights be below the axis of rotation of the whole ſyſtem. Third, The further the weights are below the axis *g h*, or the point *b*, the greater power will they have to recover the vertical poſition of the figure. Fourth, The nearer the weights are to the point *b*, or line *g b*, the leſs will be their power to recover the vertical poſition of the figure; and they have no power at all when the weights are placed in the line *g b*. Fifth, When they are placed above the pivot, they will both contribute to overturn the figure; and the greater their diſtance above the figure, the greater their force to overturn the figure. In order then to keep

keep the figure in an equilibrium, the center of gravity of the counter weights muſt be placed below the extremity of the pivot.

This important point, which M. *Bouguer* calls the metacenter, might eaſily be found in floating bodies, if the center of their motion were invariable and known.

It is not my intention to follow M. *Bouguer* through the various ſteps of his elegant inveſtigation of this point. We ſhall here obſerve, that there is a great difference betwixt M. *Bouguer*'s metacenter and the point of rotation of floating bodies. Though, in *Fig.* 60, they be exactly the ſame, yet in floating bodies it will be quite otherwiſe; and it is poſſible the point of rotation may be continually ſhifting, from the time the body begins its vibrations till it arrives at ſuch a ſtate as renders them regular; but it is not ſo with regard to the metacenter, as M. *Bouguer* has proved beyond diſpute; and *c* is certainly the metacenter, in *Fig.* 61, for the ſub-merged part is ſuppoſed perfectly round.

In order to apply what has been ſaid to ſhipping, let us examine the caſe of a cylinder (*Fig.* 62.) lying in the water, of which let *a b d* be a ſection perpendicular to the axis; let *e b f* repreſent the hold, which contains the ballaſt, &c. *e a* and *d f* repreſent the upper works; *e f* the line of flotation, and *b* the maſt, of the ſame ſpecies with the ſhip.

It was before proved, in Chap. VIII. of the Appendix, that the weight of the whole ſhip, including maſts and rigging, and all above water, as well as all below water, was equal to the weight of that column of water diſplaced by the ſub-merged part. Now, *g*, the center of gravity of the whole ſhip, and likewiſe *i*, the point where the preſſure of the water is united, muſt both be in the vertical plane *b b*; *s* muſt always be in the center of gravity of the ſub-merged part *e b f*, ſuppoſed homogeneous; or, which is the ſame thing, the center of gravity of the column of water diſplaced by the ſub-merged part.

It is evident that if, by bad ſtowage, the center of gravity of the ſhip be in *k*, and that of the preſſure of the water in *i*, the ſhip would incline ſo far to *e*, till the two centers, *k* and *i*, ſhould be in the ſame vertical *l m* (*Fig.* 63.) the ſhip would then come to her bearings, and lay faſt in the water, but in a very bad condition for ſailing.

Now, as the ſection of the cylinder *e l f*, when it is inclined, is ſimilar and equal to the ſection *e b f*, when upright, it will follow that *i*, the center of preſſure of the water, will be in the vertical *l m*; for it will always be in that line which biſects the line of flotation. In this caſe, the metacenter does not ſhift, becauſe the ſection being a circle, all the verticals will paſs through the center; tho', in any other form, this

point

point would ſhift higher or lower, according to the inclination of the body: But it may be found by M. *Bouguer*'s method, the inclination being given.

It will be proper here to remark, that the center of gravity of the ſhip will always continue in the ſame point, even when the ſhip heels; for if it ſhould happen to be otherwiſe, by the ſhifting of the ballaſt, or any other accident, it would be of very dangerous conſequence. If then the center of gravity be in *g* (*Fig.* 62.) in the line *b h*, it will continue in that line, when the ſhip lays over, as in *Fig.* 63; for it will not be in the vertical *l m*; but it will endeavour to place itſelf in that poſition; and the force of the preſſure of the water, exerting itſelf in the direction of the line *l m*, both theſe efforts united will contribute to right the ſhip; and this will always be the caſe, if the center of gravity, *g*, be not placed above the point *c* towards *b*; for, in that caſe, the weight of the ſhip, and the preſſure of the water, would both contribute to heel the ſhip.

We may, without having recourſe to M. *Bouguer*'s geometric nicety, ſhew how dangerous it would be, to raiſe *g*, the center of gravity of the ſhip, to any conſiderable height above *i*, the point where the preſſure of the column of water diſplaced is united, as in *Fig.* 64, if the center of gravity be placed in *n*, no ſooner does the ſhip begin to heel; never ſo little, but the force of gravity acting in the direction of the line *n o*, will cauſe her to heel more, at the ſame time that the preſſure of the fluid, united in the point *i*, acting in the direction of the line *i p*, will ſtill raiſe the body higher; and both theſe forces will continue to act in concert, till they both come to be in the ſame vertical *b n*. It is now very plain, the more we raiſe the center of gravity towards *b*, the more we lower the center of preſſure of the water towards *b*, the greater force will theſe two powers have to overſet the ſhip: It is likewiſe plain, that if the center of gravity were placed in *c*, it would contribute nothing either to heel or right the ſhip. Laſtly, the nearer we come to *b*, the more will it contribute to keep the ſhip upright; and when the center of gravity is below the center of preſſure of the water, theſe two will act in concert to keep the ſhip upright.

The center of gravity muſt not, at any rate, be placed above the point *c*, which M. *Bouguer* calls the metacenter; but it will be proper here to remark, that C, the center of the arch *e b f*, (*Fig.* 61.) will ſerve to limit the center of gravity, even when the body is ſo light as to ſink only to *g h h*, in an upright, or to *i l k*, in an inclined poſition; It is eaſy to perceive, that if the center of gravity be in the line *l m*, any where

where betwixt *c* and *m*, the nearer it is placed to *b*, the greater power will it have to bring the ſhip upright, by ſtruggling to bring itſelf into the line *lb*; on the contrary, if it be placed betwixt *c* and *m*, the nearer it is to *m* the greater power will it have to overſet the ſhip.

The center of gravity, then muſt not be placed above the point *c*; but the ſhip may continue upright, tho' it be placed above *n*.

The misfortune is, that it is only ſegments of circles that have their metacenters in their centers, and could they be as eaſily found in ſhips it would be a great advantage: It is true, M. *Bouguer* has furniſhed us with a method to inveſtigate the center of gravity, of a hull in form of a ſpheroid; but it is not my intention here to follow him in his reſearches, which he has carried on with all the clearneſs they are capable of.

As we confine ourſelves to what is directly applicable to practice; it may ſuffice to have ſhewn what effect the weight of the ſhip, and the preſſure of the water will have upon the ſtability of the ſhip, and that, by what we have collected from M. *Bouguer*, we may conclude that the metacenter ſhould be placed a little above the line of flotation; but the center of gravity will be higher or lower according to the form of the bottom, or according to the manner of ſtowing the hold.

At firſt ſight, it is certain that all the weight above the line of flotation helps to make the ſhip crank, and of conſequence, the lighter the upper works the ſtiffer the ſhip, and it is by this method of lightening the upper works, that M. *de Goyon*, captain of one of his majeſty's ſhips; made thoſe ſhips carry ſail which were before thought to be very crank.

The builders may vary the form of a ſhip, chiefly, in three dimenſions, *to wit*, length, breadth, and depth: Let us examine how far enlarging of ſhips, in any of theſe particulars, will contribute towards making her carry ſail.

If the length only, without altering the other dimenſions, be enlarged, the center of gravity and the metacenter will continue the ſame height, ſo her ſtability in reſpect of inclination to one ſide will increaſe in proportion to the weight of the ſhip; and as the weight generally increaſes or diminiſhes in proportion to the length, we may ſay, that in ſhips that differ only in length, their ſtability will be in proportion to their length.

It will be quite otherwiſe, if we alter the breadth, for, by enlarging we gain, and by diminiſhing the breadth we looſe a great deal of the ſtability; M. *Bouguer* has proved that the ſtability increaſes in proportion to the cubes of the breadths. For, ſuppoſing the bottom homogeneous. then, 1ſt. The increaſe of weight, and of conſequence of ſtability, will be double the increaſe of the breadth. 2d. The additional weight will act with

with ſo much the greater force, as the length of the lever is increaſed, or as the metacenter is raiſed, and the height of that point is augmented in proportion to the ſquare of the breadth; hence, the ſtability will be increaſed in proportion to the cube of the breadth: For example, without altering the other dimenſions, let the breadths be doubled, we thereby double the weight, which, acting upon the arm of a lever, double the length will be quadruple, ſo the ſhip will acquire eight times the ſtability. We may prove this by an experiment upon two models, the one double the breadth of the other; if a ruler *b l* (*Fig.* 65) be erected perpendicular in the middle of each, and a plumb line faſtened thereto, and if likewiſe an equal weight *n*, be ſuſpended to each lever *b m*, we ſhall find, by the angle the plumb line makes with the ruler, the ſtability will be as 8 to 1. We may likewiſe prove it, by comparing the different angles made by the ſame weight, or which, perhaps will be more ſimple, let the inclinations be equal, and, ſuppoſe the one model three times the breadth of the other, then we ſhall find that it will take 27 times more weight to produce the ſame inclination, or the ſame weight placed 27 times further from the axis than the other. Hence, in general, the ſtability will be in proportion to the cubes of the breadths, provided all the other dimenſions be equal, ſo if the breadth be as 1 to 3, the ſtability will be as 1 to 27, for 27 is the cube of 3.

Experience has proved to the builders what theory has demonſtrated to M. *Bouguer*, for without doubt it is for that reaſon they place the extreme breadth of the midſhip frame pretty near the line of flotation. It would be very inconvenient to raiſe the breadth in midſhips; but by raiſing the breadth afore and abaft we gain in ſtiffneſs. This will appear very plain, if we compare the ſection that forms a rectangular parallelogram at the load water-line to one that forms a rhomboides, whoſe acute angles are at the ſtem and poſt, which M. *Bouguer* has proved to be four times the ſtability of the other. Now when, by increaſing the breadth, the water lines become leſs fair, and therefore meets with more reſiſtance in dividing the fluid, it will not from thence follow that will hinder her failing; on the contrary, as ſhe will thereby carry a great deal more ſail, it may aſſiſt her going.

We have hitherto conſidered the bottom as homogeneous, but it is evident, the ſtiffneſs of a ſhip very much depends on ſtowing the hold, as the center of gravity may thereby be lowered.

If we only increaſe the depth, without enlarging either the length or breadth, all the ſtability we can gain will be in the ſtowage; which is the next thing to be conſidered.

The feamen know very well that a fhip will not carry a ftout fail till loaded fo deep that the furface of the water may glance on the extreme breadth in midfhips, as the line *e f*, (*Fig.* 65.) or a little above *c d*, (*Fig.* 66.) and that they muft have a great deal of weight, fuch as ballaft, dinnage, &c. which ferves for no other ufe, but to bring the fhip to a proper trim in the water; for if fhe be too light, as in (*Fig.* 66.) fhe will lay over till her extreme breadth *g* refts upon the water; hence it follows, that a fhip that carries a good fail will heel but little, and ply well to the windward; but if, for want of ballaft, the fhip be not loaded quite fo deep, if fhe wants but a little, it will be no great difadvantage, for after fhe once comes to lay over to her breadth fhe will go no farther, and fhe will fail very well in that pofition.

There will be great danger in overloading a fhip, for then her guns will not be a proper height out of the water, an article of great importance, and fhe would meet with more refiftance in paffing thro' the water; for, admitting her to be loaded to the line *o i*, (*Fig.* 65.) fhe would difplace no more water by heeling to the fide *o*, and fo the preffion of the water would not contribute with the center of gravity to bring the fhip upright.

I fhall not prefume to determine this point to a nicety, fo as to admit of no exception. It may fuffice to fay in the general, that a fhip fhould be loaded to her extreme breadth; but it is not indifferent what manner of ballaft we ufe, for the quality and ftowage of the ballaft may very much increafe, or diminifh, the ftability. It is evident then we muft have no more ballaft than will load her to the extreme breadth; fuppofing 400 tons, together with provifions, &c. to be fufficient to load a fhip to her breadth, we muft put no more weight on board, but we may take heavier ballaft, by which means the center of gravity will be lowered proportionally to the fpecifick gravity of the ballaft. Hence is deduced the general practice of ftowing the heavy goods lowermoft, and the light uppermoft, whereby the fhip will be able to carry the greater fail.

It is not a matter of indifference how goods are ftowed in the hold; for, fuppofing a fhip loaded with lead, guns, iron, or and other weighty goods, her hold would not be near full, when loaded to her proper water line; and tho', by placing thefe goods on the floor, the fhip would certainly carry a great fail, yet fhe would fail very badly, and be in danger of being difmafted by her prodigious rowling and fudden jirks.

The mariners finding by experience how dangerous this would be have in a great meafure, found means to prevent it by the dinnage, whereby the

the heavy goods may be raiſed, this will make her rowl eaſy, and go ſmoothly thro' the water.

What we have ſaid of the ſtability of ſhipping has inſenſibly led us to conſider the rowling and pitching; we have already ſhewn that the rowling may be very much prevented by ſtowing the hold; the form of the bottom may likewiſe contribute thereto.

To explain this by an example; let us ſuppoſe the ſection of a ſhip, perpendicular to the keel, to be exactly round as (*Fig.* 63), it is plain, if this be agitated in the water, it will have nothing to ſupport it, becauſe it diſplaces no more water when inclined than when upright, and of conſequence would rowl prodigiouſly. But if we put a plank below *b*, ſuppoſe to *g*, to run quite fore and aft, it is plain, when the ſhip is inclined to the right, the plank *g* will diſplace a column of water to the left, which will retard her motions, and this obſtruction will always act contrary to the way the ſhip heels, and will very much diminiſh the rowling, but will add very little to her ſtiffneſs; for, admitting the ſhip to heel as in (*Fig.* 63.) the plank *b g* would contribute very little to bring her upright. But the depth of the keel, the riſing of the floors, and the dead wood fore and aft, as in (*Fig.* 66.), will anſwer the ſame purpoſe as the plank *b g*.

In regard to the pitching, I am of opinion, the beſt method that can be taken will be to proportion the capacity of every part to the weight it is to contain, and it will be very dangerous to depart from this rule; we have an inſtance of it in the *Juno* of 60 guns, which, wanting capacity abaft, was always a very bad ſailer; and, notwithſtanding all proper means were uſed to remedy this, by moving the iron ballaſt forward, and the fore-maſt guns aft, yet all their endeavours proved unſucceſsful, for ſhe ſometimes pitched to that degree, that her counter was under water.

It would not be adviſeable to build a bad ſhip on purpoſe to try experiments; but when we find a ſhip that has ſome bad qualities, it will be of ſingular uſe to find the proper means to remedy the fault.

In order to comprehend the means to be uſed to prevent the bad conſequences of violent pitchings, let us ſuppoſe a ſhip at reſt, and a ſea taking her afore; if the bow be well ſupported; that is to ſay, if the foremoſt frame be pretty full, and her breadth line of the riſing of the floor not carried too high, this veſſel will infallibly riſe with the ſea; it is true, when the ſea leaves her ſhe will fall again, but it will be eaſily, becauſe the breadth increaſes gradually, even above the load water line; and this ſwelling of the body, being gradual, will hinder the ſhip from falling with ſudden ſhocks; on the contrary, if ſhe be very ſharp forward, ſhe will not pitch ſo much, but ſhe will, in the ſea term, bury herſelf under water forward, ſo that the foremoſt guns will be entirely unſerviceable in a ſea-gate.

We may perceive then, that their are two rocks to be avoided; though the breadth muſt be carried above the load-water line, to ſupport the bow that ſhe may riſe to the ſea, yet it muſt be divided in parts to prevent violent pitchings.

Let us ſtill conſider the ſhip pitching, or heaving and ſending, in a ſea-gate; if the foremoſt frames have no hollow, that is, if they be ſtrait, from the breadth to the rabbit of the keel or ſtem, or if the vertical curve reſembles a wedge, thoſe ſhips will fall eaſy, becauſe the breadth, increaſing gradually, the reſiſtance will likewiſe be gradual; but, on the contrary, if they are very ſharp below, and the frames form a hollow from the rabbit almoſt quite as high as the breadth, it is plain ſhe will meet with a very ſudden ſhock, as the ſea meets with no oppoſition, till, all of a ſudden, it is reſiſted by the breadth; ſo that, in general, it is leſs dangerous to have a full bow, which will riſe to the ſea, than a very ſharp one which will plunge the ſhip's fore-caſtle in.

Hence, the whole art conſiſts in finding the proper mean betwixt theſe two extremes; that is, to give the ſhip ſuch a form as may riſe and fall eaſy into the ſea, and likewiſe not hinder her ſailing.

We have now given our readers the ſubſtance of what theſe two eminent mathematicians have ſaid on the theory of Ship-building, and for further particulars, beg leave to refer them to the originals; they will then be able to judge how far they have ſucceeded in determining the neceſſary *data*; one thing may be remarked, that they at laſt refer us to experience, but experience ſeems not to agree with M. *Bouguer*'s principle, on which he ſays the velocity depends: For he aſſerts, that if the midſhip frame be carried before the middle of the ſhip, it will obſtruct the velocity; becauſe the bow will thereby become fuller; however he places it at one twelfth of the length before the middle, to give the helm more purchaſe.

I ſhall now give our readers an account of ſome experiments taken by one of our own countrymen, whoſe abilities are unexceptionable. He, by long experience, and unwearied application, has made ſeveral uſeful diſcoveries, which baffled the deepeſt reſearches of the moſt eminent mathematicians; his experiments prove beyond diſpute, that we ſhall gain in point of velocity, in carrying the midſhip frame before the middle, perhaps

at

at two thirds of the length from the after end. I ſhall not take upon me to aſſign the reaſon of this, but there is no diſputing againſt matters of fact, perhaps it may be owing to what I ſaid on that head, when treating of towing a maſt, butt end foremoſt, or it may be on account of the center of gravity, which will thereby be further forward; it muſt be allowed this laſt circumſtance will give the helm more purchaſe, tho' it cannot be diſcovered by his experiments, the whole deſign of theſe experiments being to determine the form of that body which will go thro' the water with the greateſt velocity, and to aſcertain the moſt advantageous ſituation of the midſhip frame, and that this muſt be nearer the fore part than the after part, he has demonſtrated in ſuch a clear, elegant, and familiar manner, that I ſhould only diſcover my own weakneſs, in preſuming to ſay any more on that head; ſo I ſhall give it in his own words.

Of the Friction, or lateral Preſſure of Water.

THE cylinders made uſe of in the following experiments were ſolids of ſeaſoned oak, 36 inches long, by four inches and a half diameter; the ſides were ſtrait, and turned exactly round.

A, in *Fig.* 74. is the ſtandard to make the compariſon from; when the pieces 1, 2, 3, 4, 5, are ſcrewed together, they make the cylinder B equal to A, theſe are drawn thro' the water with the end 5 foremoſt; until (by encreaſing or leſſening the weight a little at the roller or pully) the velocities agree.

After which take out 2, and put together 1, 3, 4, and 5, which makes the figure C to be one fourth part ſhorter than A, at which time it gains the velocity of one eighth.

Then take out 3, and put 1, 4, 5, together, and it makes the cylinder D; which being drawn againſt A, as before, it makes the velocity one fourth part more.

After which, if we join 1, 2, 3, 4, and 6, together, it makes the cylinder E, with no more difference from A, only that there is a direct flat ſuperficies in lieu of a convex; this drawn againſt A, loſes in velocity one ſixth part.

Take off 6 and join 7; it makes the figure F, a concave, and, when drawn as before, it loſes one fourth part of the velocity.

When the flat ſuperficies is drawn hindermoſt, it loſes one twenty-fourth part. When the concave is drawn hindermoſt, it loſes the ſame one twenty-fourth part.

From

From ſuch experiments, we may gain a proportion for lateral preſſure, or friction; we alſo ſee the great difference between a convex and a flat ſuperficies to ſeperate the water; and the difference between a concave end to ſeperate the water and a flat ſuperficies; alſo between a concave and a convex end; and alſo, that there is a ſenſible difference as to its ſeperating the water, by being foremoſt, tho' not ſo by the cloſing in of the water by being hindermoſt.

Theſe things may be of ſervice in theory, and ſeem capable of being improved by further experiments.

NOTES *relating to* EXPERIMENTS.

Method for knowing the lines of leaſt reſiſtance. Intended for the purpoſe of forming the bodies of ſhips; alſo, relating to an attempt for finding the proportion for the friction or lateral preſſure of water.

Provide a ciſtern for the water as repreſented in the plate (*Fig.* 75), not leſs than 30 feet long, and divide it in halves by a partition length ways, that the motion of the water in one part may not diſturb that in the other; obſerve, as the leaſt blowing of the wind diſturbs the ſurface, it is beſt to be under cover, namely, in a ſhed or warehouſe.

Obſerve the pullies, repreſented on the plate, be made very exact, the lines may be ſilk or *Indian* graſs.

There muſt be alſo a line ſtrained very tight over the middle of each water, and wires fixed upright in the end of each block or ſolid; which by the ends, turning back over the line, keeps the block or ſolid direct in its courſe.

At each end of the block is fitted a ſmall ſtaple, by which the lines faſten with a hook to draw the block; there muſt be time given between each drawing for the water to become ſtill.

The blocks muſt be as near as poſſible equal in weight, and ſwim truly level with the ſurface of the water; if they do not, it muſt be remedied by cutting out a ſmall piece, or by making a groove in the ſolid, and ſo trim the block by putting in ſmall ſhot: The whole will require much care and exactneſs.

The figures repreſent ſolids, whoſe lengths are 2 feet 3 inches, and diameters ſomething leſs than one third of their lengths; theſe are made perfectly round, one end of theſe ſolids is of one ſhape, the other ends vary as the figures repreſent.

The quantities and weights are made equal and drawn thro' the water, with equal power, that is, firſt make the ſtandard ſolids agree in velocity, then fix equal weights to the lines that paſs over the rollers.

Whoever repeats theſe, or proceeds in making other experiments will do well to obſerve, what weight nearly he chooſes to uſe; for, if the power is very ſmall, a little obſtacle may impede the motion of the ſolids too much. If the weight is great, the velocity will be too much for the obſerver to decide with exactneſs the difference of velocity between the two moving ſolids.

POSITION.

Theſe blocks being perfectly round, and as the water preſſes on bodies in all directions, therefore, theſe blocks are truly repreſented by ſingle lines in the figure A, B, C, D, in (*Fig.* 76.) and without having other lines of different curves intermixt with them; ſo that which ſoever of theſe ſolids ſhall have the greateſt velocity, has ſo far the lines of leaſt reſiſtance.

EXPERIMENT.

There were two blocks or ſolids repreſented by figure A, of equal weight, ſize, and velocity. This velocity was made equal by altering a little the weight that paſſes over the braſs roller; one of theſe ſolids is made a ſtandard to try the other, otherwiſe we could not have known ſo perfectly which end foremoſt, of A, would have the greateſt velocity.

	Reverſe the ends.
A drawn againſt A equal velocity.	H againſt A loſes about one 27th.
B againſt A gains in velocity about one 16th.	G againſt A loſes about one 16th.
C againſt A loſes in velocity about one 70th.	F againſt A gains about one 14th.
D againſt A gains in velocity about one 9th.	E againſt A loſes about one 9th.

Obſerve, that if the braſs rollers are not exact, they will affect the motion of the ſolids; ſo that it is proper to change each ſolid, together with its weight, over each roller, for the ſame reaſon we change the weights to try ſcales. The roller which upon careful trial appears to increaſe the effect of the weight may be leſſened in the circumference, or the other increaſed in the circumference.

D hath the greateſt velocity, I ſay it is becauſe the breadth declines nearer the head than in the others, which eaſes the lateral preſſure ſooner than in the others. The extreme breadth of the figure

figure B, is nearer the end, which breaks open the water fooner, but then the breadth is continued further aft, by a ftrait fide, fo that the friction is not eafed by the declining of the fides fo foon as in D, and therefore the difference in velocity is accounted for as before.

Experiment with the Solids I, K, L. (Fig. 77.)

I, and K, are two diftinct blocks, the extreme breadth of each is in the middle; they are equal in quantity, equal in length, and equal in weight, but not equal in breadth. The block K is narrower in the middle and fuller towards the ends: The block I is broader at the middle, and narrower towards the ends; they are drawn, and found that K hath more velocity than I, by one forty-fixth part.

L is the fame length, fame breadth, fame quantity as I; the extreme breadth of this is removed from the middle to one third of the length from one end, by which means one end is fuller, and the other juft fo much the fharper, and the floor fhorter; this drawn, the full end foremoft, againft I, gains in velocity one ninth part, and when the fharp end is foremoft, it lofes one ninth part.

Doth not this fhew, that if a fhip was built with the lines that form the body fimilar to the folid whofe breadth is in the middle, and if another was built with the lines that form the body fimilar to the folid whofe breadth is one third from the ftern, the latter would lofe of the former one ninth part of the velocity?

If another fhip was built, whofe lines that form the body were fimilar to the folid whofe breadth lay at one third from the head, it would outfail the fhip whofe breadth lay in the middle one ninth part. Alfo, that the fhip whofe breadth lay at one third from the head, would outfail the fhip whofe breadth lay at two thirds diftance from the head, two ninth parts of the diftance run.

The abfolute and relative force of a current of water, againft the forepart of a fhip, may be computed from the fines of the angles of incidence taken in many parts, as is defcribed by M. *Duhamel*, or fome other way equal thereto, as far aft as the midfhip frame; and as the midfhip, or the wideft frame may be placed in the middle, or further aft or further forward, and the quantity of the bulk remain the fame in the whole; fo by moving the midfhip frame further aft, the lines that form the fore end of the fhip thereby runs nearer a parallel to the keel, and confequently have the lefs abfolute refiftance to the current of water; but this accounts but for one part only, that is the refiftance of the cur-

rent

rent from the ſtem to the middle of the ſhip. Yet there is a friction, if I may ſo call it, from the lateral preſſure of the water againſt the ſides and bottom of the ſhip that muſt be conſidered alſo, which I will endeavour to explain in the manner following. Water, according to its depth, is by its own weight compreſſed together, againſt the ends, ſides, and bottom, in all directions; if the body placed therein be not ſpecifically heavier, the water will bear it up, and, in proportion, as the body is lighter, the more it will float out of the water; this is familiarly known, but the applying this to the preſent purpoſe may bear ſtating in this manner.

Water, or any liquid, placed in a box, or veſſel of any figure, preſſes againſt all the ſides with a force equal to its depth, and, at the ſame time, the whole weight on the bottom. On the contrary, when a veſſel is placed in water, the water preſſes the ſides and ends inwards, and upwards, under the bottom, with a force to bear up the veſſel, ſhip, or any other figure whatever, that is not ſpecifically heavier than the water.

The moving this body, as it is thus circumſtanced, with the water preſſing againſt it on all directions, muſt put all the parts of the water that are next, or near it, in a ruffle and ſort of confuſion; the particles at the fore-end of the ſhip, near the bottom plank, appear to be conſtantly removed by freſh particles of the current preſſing in, and impelling againſt them, and ſo one after another; but when we come to a more ſtrait part of the ſhip's ſides, and the declining part of the ſhip's bottom, the particles next the plank are not ſo ſoon diſpaced; this appears, from obſerving the graſs that grows on the ſides of the ſhip; it ſhall be ſeen to grow right out, and wave backwards and forwards, from the ſides of the ſhip, as if the water had no motion, when at the ſame time, the ſhip may be ſailing three four or five knots an hour, or more: This is, in part the caſe when the ſhip's bottom is clean, but much more ſo when the bottom is foul. This atmoſphere, or carrying part of the water along with the ſhip, is what I have here called friction, and is to be conſidered, and muſt be taken into the account of the reſiſtance. In order to form ſome conception thereof, the ſolids, repreſented by the figures, were contrived, being turned exactly round, and the water preſſing in all directions, they are by me eſteemed as ſingle lines.

By theſe experiments, it appears, that by moving the middle frame from the middle, nearer one end; that end unto which the wideſt frame is neareſt, gives the greateſt velocity, when turned foremoſt, and ſo contrariwiſe it is reverſe.

Now it is plain, that by fo doing, the entrance of the ſhip doth make a more ſudden, or is of more abſolute force againſt the current of the water, than when in the middle of the ſhip, or ſolid, on which the experiment is tried. To account for this, I am ſatisfied with conceiving that by moving the midſhip frame nearer the fore-end of the ſhip than in common is done, the body thereby declines ſo much ſooner, and takes off part of the friction cauſed by the lateral preſſure, which appears to be of more ſervice to the velocity, than what is loſt by making the fore part of the ſhip ſomewhat fuller.

To inſiſt that the difference in velocity of theſe experiments, as ſet down to that account, is exactly neither more nor leſs, than what is there mentioned, may not be ſtrictly or ſcrupulouſly true, but that it is near the truth is demonſtration; and it hath been long ago ſhewn by Sir *Iſaac Newton*, that a blunt headed figure, impelled in the direction of its axis, was the ſhape of leaſt reſiſtance in a fluid; but the propereſt proportion between the length and breadth is not deduced.

In the next place it reſembles nature, in the form of the faſt ſwimming fiſhes, and hath been experienced with ſucceſs; from all which it is become to me a rule, or pattern, that, ſo far as other conſiderations will admit, the lines that form the bodies of ſhips ſhould be ſimilar to the pattern that had the greateſt velocity.

Suppoſe a cruiſing ſhip had all the perfections in her dimenſions, and every other part, and the midſhip or broad-ſide frame placed near the middle of the ſhip, and built ſharp at the ends; conſider the weight of the fore-maſt, rigging, and ſails, belonging to her; the anchors at the bows, which, with the preſſure of the wind into the ſails, all unſupported but from the body farther aft, and united to preſs down into the hollow of every ſea; I ſay, for want of more body further forward, ſuch a ſhip muſt plunge deep, and hinder the velocity; this is not the caſe of the hinder part of the ſhip. Another conſideration is, the ſide reſiſtance of the bottom of the ſhip muſt not be equally forward to that abaft, for, if it was, the ſhip muſt be trimmed greatly by the ſtern, or her rudder would not command her, to bear up in a gale of wind. When a ſhip is preſt with ſail, the water is forced up at the bow, a little above a level, and the ſhip is preſſed a little down, which amounts to the ſame, with reſpect to her helm, as if the ſhip was trimmed by the head. Then ſhips that carry their tilier near the middle in light winds, require it more a weather, when it blows. Suppoſe, by moving the midſhip frame a little farther forward than M. *Duhamel* propoſes, and is commonly done,

if

if it did not add to the velocity, by ſo doing, provided it retard not the motion, it is of ſervice for the reaſons mentioned.——So far theſe Experiments.

We may now venture to aſſert, that by carrying the midſhip frame forward, as in the preceding experiments, we ſhall gain, not only in point of velocity, but likewiſe, according to M. *Bouguer*'s own principle, in point of ſteerage, which will be a double advantage.

As theſe experiments were made in ſtill water, it may be preſumed, when a ſhip is to encounter a great head ſea, there will be at leaſt as much, if not more occaſion for a full bow.

The Method of bevelling the Cant Timbers by the Diagonal Ribbands, and likewise the Fashion Piece of a Square-Tuck, by Water Lines.

* *To bevel the Cant Timbers by Ribbands.*

THE angle F *o b*, (*Plate* VII. in the foregoing treatise) will be the angle which the fashion piece will make with the third ribband: For *o* being the point where the plane of the fashion piece intersects the third ribband; a line drawn from *o* to F, will be the line in which the plane of the timber intersects the plane of the ribband: But then, as these planes are not perpendicular to one another, the angle F *o b* will not be the true bevelling, unless the bevel be so applied that the tongue may be in the direction of the ribband, and then the stock cannot lay flat upon the side of the timber: For which reason this method will not do for practice; for the surest way to take any bevelling, is when both the stock and the tongue of the bevel are square to the timber.

In order then to find the true bevelling upon a square, the direction in which the ribband intersects the timber must be given, as well as the angle F *o b*; and likewise the breadth of the timber: Now if these three be given, the angle upon the square may with certainty be found by the follow method.

Let the distance betwixt the parallel lines A B and E F be the breadth of the timber; B *a* the direction of the ribband; and *a b* what the bevelling is without a square. (*See the* Fig. *under the* Scale, Plate VII.)

Now, that we may the easier conceive how this bevelling may be found, let us suppose the timber to be quite strait, suppose the partition of the chest, *Page* 124; and first trimmed square. Then, because *a b* is what it is without a square, it is plain there must be so much lined off the aft side of the timber; the line *a* B will be the breadth of the outside of the timber, in that direction before the wood is taken off; and if B D be made equal to B *a*, and D *d* equal to *a b*, and the angle at D a right one; then it is plain the angle A B *d*, equal to the angle F *o b*, will be the bevelling, if the tongue of the bevel can be kept in the direction of the line B *a*: But when the stock of the bevel is laid flat on the side of

* These directions are again inserted in the *Supplement* for the benefit of the Purchasers of the first Edition.

the

the timber, the tongue will naturally be perpendicular to the plane of the timber, which will be in the line B F; and if F f be made equal and parallel to D d; then will the angle A B f, be the true bevelling upon a ſquare.

DEMONSTRATION. (*Plate* VII.)

In the right angled triangle a F B, B F the breadth of the timber is given, and a B the common ſection of the plane of the ribband, with the plane of the timber; again in the right angled triangle b a B or B D d, its equal, we have a B or B D the breadth of the timber in the direction of the ribband, when the timber is yet ſquare, and b a, or D d, what the bevelling is without a ſquare, ſo the angle A B D will be the bevelling.

But if B F were the common ſection of the ribband, and timber, then the line of direction would be ſquare to the timber, which does not alter what the bevelling is without a ſquare, *viz.* the line a B or D d.

In the right angled triangle F B f, F f, and F B are given, hence we have the angle A B f, the bevelling on a ſquare; but it is plain the ribband will be higher on the aft than on the fore ſide, when in the after body, and the contrary when in the fore body; therefore the heighth of the ribband muſt be transferred from the contra to the moulding ſide, which muſt be the firmark when the bevel is ſquare to the timber; ſo the firſt thing to be done, is to find the height of the ribband, on the contra ſide, for its heighth on the moulding ſide is given before the timber can be formed.

Before we give direction how to find this, it will be proper to obſerve, firſt, that tho' the planes of the ſquare timbers interſect the planes of the ribbands in the diagonals, in the body plane, yet the cant-timbers do not, for the plane of the 4th ribband cuts the plane of the faſhion piece, in the line r F, and not in the line r s. Secondly, we muſt remark, that the breadth of the timber muſt be determined, which, ſuppoſe F e in the floor plane, ſo ſhall r B repreſent the foreſide of the faſhion piece, on the floor plane, it being parallel to F P, which repreſents the aft ſide: Let F e be ſquare to the point F, ſo the fore ſide of the plane of the faſhion piece muſt be broader than the aft ſide, by the length of the line B e, that being what its bevelling to the ſheer plane is without a ſquare; this being premiſed, we may find the heighth of the third ribband, on the contra ſide of the faſhion piece, and from thence find the bevelling of the cant timber by the following method:

1ſt.

1*st*. Take B *e*, that is, what the fore ſide of the plane of the faſhion piece is without a ſquare; ſet this off on the perpendicular *r d*, in the body plane, and draw the line *d d* parallel to K O.

Note. The line *d d* will be in the fore body for the after cant timbers, and in the after body for the fore cant timbers.

2*d*. Produce the common ſections of the planes of the ribbands, on the aft ſide of the faſhion piece, to cut the line *d d*, as F *r* in the plate meets the line *d d* in *e*.

3*d*. From the point *d* draw a line parallel to *r* F, which will be the common ſection of the plane of the ribband and the plane of the foreſide of the faſhion piece; uſe the ſame operations for finding the other ribbands, as you ſee in the plate, and call them new diagonals.

4*th*. Find points in theſe new diagonals thro' which the curve of another cant timber would paſs, this will be the fore ſide of the faſhion piece, obſerving that the lines taken from the floor plane muſt be ſet off from the line *d d*, and not from the line K O; the diſtance of theſe points from the curve of the aft ſide of the faſhion piece will be what the bevellings is, within or without the ſquare. In applying the bevel, the ſtock muſt be laid on the new diagonals, but when this is not ſquare to the timber, take the neareſt diſtance to the curve of the moulded ſide of the timber from the foreſaid points, and there place the firmark, ſo the ſtock and tongue will be ſquare to the timber, as in the firſt ribband, and from theſe points make an exact bevelling board, as in the plate; the like proceſs may be uſed for the fore body.

The difference of the heighth of the ribbands on the moulding, and contra ſide, may be had by projecting the planes of the diagonal ribbands on the ſheer plane. The forms and bevellings of all the other cant timbers may be had by the ſame method, but every timber will require another line, for the line *d d* will fall betwixt that and the line K O, till at laſt it coincides with it, that is, when the timber has no cant, and the new diagonals will be approaching to thoſe that repreſent the planes of the ſquare timbers in the body plane.

The cant timbers may likewiſe be bevelled by water lines; their planes are repreſented by level lines in the body plane, which, in ſome caſes, will be very oblique to the curve of the timbers, but this may be reduced to a ſquare, and the bevellings found as before directed: See that of the firſt tranſom in the plate.

To bevel the faſhion piece of a ſquare tuck by water lines.

The faſhion piece of a ſquare tuck may bevelled by water lines, in the ſame manner the cant timbers are by ribbands, for as it both rakes and cants,

cants, the planes of the water lines will interfect it higher on the aft than on the forefide; and, before we have their heights on the forefide, the breadth of the timber muft be determined, which fuppofe *b n* (*Fig.* 71.); but this is not all, for, as it cants, the breadth in the direction of the water line, will be more than the true breadth: In order to find the true breadth, form the aft fide of the fafhion piece, as directed in page 140; but, as we intend here to allow for the thicknefs of the plank, we fhall alter both the rake and cant.

Let *t* 5 (*Fig.* 69.) be the aft fide of the rabbit on the out fide of the poft; W M the common fection of the plane of the fafhion piece, and fheer plane; but before this laft line can be determined, draw the feveral water lines 1, 2, 3, 4, and 5, parallel to the keel, which may reprefent fo many tranfoms; let all thefe water lines be formed and ended at the aft fide of the rabbit, as in *Fig.* 70, where the round aft of the tranfoms is defcribed, and limits the curves of the water lines. Now the line W M muft rake fo as to leave room for half the thicknefs of the poft at the tuck; in order to which, produce W *g* to *r*, make *r g* half the thicknefs of the poft, thro'. *r* draw a line parallel to *g* M, to interfect *g* G in *b*; with the radius *r b* from *x*, the point of the tuck as center, defcribe an arch, and draw the line W M juft to touch the back of that arch.

The lines parallel to *g* G muft likewife be fo drawn as to cut off no part of the tranfoms in (*Fig.* 70.) the lines *g* G, *a* 4, *s* 3, are abaft the ends of the tranfoms, fo all that wood muft be taken off after the fafhion piece is bevelled.

Having thus drawn the line W M, firft affume any point *k*, at pleafure; in the line W M, *Fig.* 69, let fall the perpendicular *k y*, and draw *y f* parallel to *g* G, to interfect a perpendicular drawn from the point M in *f*, *Fig.* 70.

2*d*. From M draw the line M 1 fquare to *y f*, and then the line *y n* fquare to W M.

3*d*. Make M *n*, *Fig.* 71, (equal to M 1, *Fig.* 70.) the bafe of the right angled triangle *k n* M, of which M *k* is the perpendicular equal to *k y*; fo the angle *k n* M will be the bevelling to the horizontal plane; and to find its bevelling to the fheer plane.

1*ft*. Make M *z*, *Fig.* 71. (equal to *n y*, *Fig.* 70.) the bafe of the right angled triangle *f z* M, *Fig.* 71, of which, *f* M the perpendicular, is equal to *f* M, *Fig.* 70; fo the angle *f z* M will be the bevelling to the fheer, as demonftrated in page 126.

Having thus found the bevellings, draw the line *a b*, *Fig.* 71, parallel to *z n*; let *z a*, equal *n b*, be the fcantling of the timber, then *n x* will be the

the breadth of timber on the horizontal, and *z c* its breadth on the ſheer plane, and *a c* what it is within a ſquare.

Now, as the lines *g* G, *a* 4, *s* 3, *b* 2, *y* 1, repreſent the aft ſide of the faſhion piece on the horizontal plane, *Fig.* 70, we may draw the dotted lines parallel to them to repreſent the fore ſide as in the plate; making *n x*, *Fig.* 71., the ſquare diſtance betwixt them, and their correſpondings on the aft ſide, and by theſe dotted lines form the foreſide of the faſhion piece in the ſame manner the aft ſide was formed; but thewater lines on the fore ſide of the plane of the faſhion piece muſt firſt be drawn, in *Fig.* 69. Thus,

1ſt. Draw the lines *e b* and *c d* parallel to W M, (*Fig.* 69.) making the diſtance betwixt W M and *e b* equal to *a c*, (*Fig.* 71.) and the diſtance betwixt W M and *c d* equal to *z c*. (*Fig.* 71.)

2d. Draw a line parallel to W F, through the point where the line *c d* interſects the fifth water line, *Fig.* 69; draw a line parallel to *a* A, through the point where the fourth water-line interſects the line *c d*. Do the ſame by all the water-lines.

We may now project the fore-ſide of the faſhion-piece by the new water-lines, obſerving that the diſtances muſt be ſet off from the line *e b*, and not from the line W M; or find the points through which the curve ſhould paſs on theſe new water-lines, and the neareſt diſtance betwixt theſe points and the curve of the aft ſide, is what the bevelling is without a ſquare, when both ſtock and tongue are ſquare to the timber; and, when the water-lines are not ſquare to the timber, reduce the bevelling to a ſquare one, and place the firmarks on the moulding edge, as you ſee in the plate, and from thence transfer the bevellings to a board, the exact breadth of the timber.

After the timber is trimmed and bevelled from the aft ſide, there will be a ſpiling, *e d*, (*Fig.* 70.) to be ſet off forward from the line G *g* produced; and a ſpiling, *c o*, from *a* 4 produced; laſtly, a ſpiling, *l m*, from *s* 3 produced; and as the aft ſide of the faſhion-piece winds, there muſt likewiſe be ſpilings ſet off for the inſide, as in *Fig.* 69.

Let 11, 12, 13, 14, *Fig.* 69, be the inſide of the faſhion-piece; make *g*, 11, *Fig.* 70, equal to W, 11, *Fig.* 69; *a*, 12, *Fig.* 70, equal to *a*, 12, *Fig.* 69, *&c.* So 11, 12, 13, 14, will be the ſpilings, and wear off at the point 1; *Fig.* 70.

There will be no occaſion to ſide the moulding ſide of the faſhion-piece quite ſtrait; it may be ſided ſo, that, when the mould is ſlightly faſtened to it, the head of the faſhion-piece may round from the mould nearly the whole quantity of the ſpiling, and then it may be bevelled from the mould, and afterwards the proper ſpilings ſet off.

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The timber being thus trimmed, the planks will come to the aft ſide of the faſhion-piece, which will make the ends apt to ſtart off with the caulking; to prevent which the thickneſs of the plank muſt be ſet off without the moulding edge of the faſhion-piece, as in the plate; and, when the faſhion-piece is bevelled to this mould, we ſhall have the whole thickneſs of the plank, without the moulding edge both of the aft and fore ſides; ſo the planks may be rabbitted into the faſhion-piece, leaving ſubſtance enough on the aft ſide to cover the ends of the planks. The planes of the timbers, in ſome caſes, cut the plank very obliquely, which will occaſion the plank to be thicker in that direction than really it is; therefore the thickneſs of the plank, in the direction of the plane of the timber, at each water-line, muſt be determined before the mould can be made. This will be a very difficult taſk; however, we ſhall endeavour to perform it in the following manner.

1ſt. Draw a line ſquare to the ſecond water-line, at the point 2, where the plane of the faſhion-piece interſects it on the floor plane, *Fig.* 70; and produce this line, from the middle line, to interſect all the other water-lines, which muſt be produced for that purpoſe; ſo the ſquare line, in *Fig.* 70, will be 2, 2, *v*.

2d. Form a cant timber in the direction, or cant of that line, as in *Fig.* 68.

3d. Set off the real thickneſs of the plank ſquare from this timber, to interſect the correſponding water-line in the point *r*; ſo *r s* will be the thickneſs of the plank on the plane of the water-line.

4th. Set off *r s* parallel to the ſecond water-line, *Fig.* 70; to avoid confuſion this was done by a pencil, and we have only the point *t* in the plate, where the plane of the faſhion-piece interſects it.

5th. Produce *b* 2, *Fig.* 70, to interſect the curve in *t*; ſo *t* 2 will be the thickneſs of the plank in the direction of that line.

6th. Produce the line *b* H, *Fig.* 69, to *q*, making *b q*, *Fig.* 69, equal to *b t*, *Fig.* 70; ſo *q* will be one point of the curve.

Though this method may be too tedious for practice, yet, as it ſeems to bear a mathematical demonſtration, we have adventured to inſert it; far from imagining that there are not other methods better adapted for that purpoſe; for, without ſome ſuch contrivance, a ſhip could not be built exactly of the ſame dimenſions with another already built, having only the dimenſions of this laſt, by taking them off when in a dock, which muſt be from the outſide of the plank; whereas, when they form the timbers, the dimenſions muſt be taken from the inſide of the plank.

On the Masting of SHIPS.

AS M. *Bouguer* has given us the general proportions for the length and diameter of masts and yards used in *France*, it may be expected we should give the proportions used in *England*.

It must be owned, the art of masting ships is quite as imperfect as that of forming the bodies, for they bear no manner of proportion to any of the other dimensions of the ships, and seem to be wholly regulated by the judgment and experience of the commanders. This will appear very plain by examining the dimensions of the masts and yards of the following ships, and comparing them with the breadths and lengths of those ships, and yet their commanders were all allowed to be expert seamen.

Dimensions of Masts for EAST-INDIA *Ships.*

	Length. Feet.	Diameter. Inches.		Length. Feet.	Diameter. Inches.
MAIN-MAST	80	24½	MAIN-YARD	66	16½
Top-mast	50	15	Do.	52	12½
Top-gallant-mast	28	8	Do.	36	6
FORE-MAST	72	24	Do.	60	15
Top-mast	48	15	Do.	48	12
Top-gallant-mast	25	7½	Do.	34	5½
MIZEN-MAST	70	17	Do.	61	12½
Top-mast	36	10	Do.	36	7½
Bowsprit	50	25	Do.	50	12
Jyb-boom	36	11	Crossjack	50	11½

Dimensions of Capt. KENNEDY'*s Masts and Yards, of about* 182 *Tuns.*

	Length. Feet.	Diam. Inch.		Length. Feet.
MAIN-MAST	62	16½	YARD	44
Top-mast	33	10	Do.	32
Top-gallant-mast	18	5½	Do.	24
FORE-MAST	56	16½	Do.	39
Top mast	30	9½	Do.	30
Top-gallant-mast	16	5	Do.	22
MIZEN-MAST	53	11	Do.	40
Top-mast	28	6½	Do.	24
Bowsprit	36	16½	Crossjack and spritsail 32 feet long;	
Extreme breadth	23		Spritsail topsail-yard 24	

Length on the lower deck from the aft side of the stem to the fore side of the stern-post } f. 81 in. 8

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Dimensions of Captain ALLEN's *Masts and Yards, about* 176 *Tuns.*

	Masts. Length. Feet.	Masts. Diam. Inches.	Yards. Len. Feet.
MAIN-MAST	63	16½	44
Do. top	33	10½	33
Do. top-gallant			25
FORE-MAST	58	16	39
Do. top	31	10½	33
Do. top-gall.			23
MIZEN-MAST	53	11½ h.miz.	
Do. top			25
Bowsprit	37	16	31
Crossjack			32

Breadth 23 f. 2 in.
Length low. deck 78 feet, 11½ in.

Capt. LYONS, *about* 167 *Tuns.*

	Masts. Length. Feet.	Masts. Diam. Inch.	Yards. Len. Feet.
MAIN-MAST	60	16½	42
Do. top	33	10	32
Do. top gall.	18	5¼	24
FORE-MAST	54	16	37
Do. top	30	9½	30
Do. top-gall.	16	5	22
MIZEN-MAST	52	11	40
Do. top	28	6½	24
Bowsprit	36	16½	32
Crossjack			32

Breadth 22 feet, 6 inches.
Length low. deck 79 feet, 1 inch.

Capt. BOWMAN, *about* 162 *Tuns.*

	Masts. Length. Feet.	Masts. Diam. Inches.	Yards. Len. Feet.
MAIN-MAST	60	16	41
Do. top	32	10	31
Do. top-gall.	17	5	24
FORE-MAST	54	15½	36
Do. top	28½	9½	28
Do. top-gall.	15	4½	22
MIZEN-MAST	50	11	20
Do. top.	25	6	25
Bowsprit	34½	16½	30
Crossjack			30

Extreme breadth 22 feet, 6 inches
Length lower deck 76 feet, 6 inches

Capt. DERRY's, *about* 150 *Tuns.*

	Masts. Length. Feet.	Masts. Diam. Inches.	Yards. Len. Feet.
MAIN-MAST	58	16	40
Do. top	31	9½	30
Do. top-gall.	18	5¼	23
FORE-MAST	52	15½	36
Do. top	29	9½	28
Do. top-gall.	15	5¼	21
MIZEN-MAST	49	11	37
Do. top	27	7	23
Bowsprit	35	16	30
Gibb boom,		7	27

Extreme breadth 22 feet.
Length l. deck 74 feet, 4 inches.

Capt. HILL, 130 *Tun.*

	Masts. Lengths. Feet.	Heads. f.	Heads. in.	Diam. Inch.	*Yards.* Len. Feet.
MAIN-MAST	55	7	6	14¾	39
Do. top	29	3	3	9	30
Do. top-gall,	18	3	0	4¾	23
FORE-MAST	50	7	0	13¾	35
Do. top	27	3	0	8½	29
Do. top-gal,	16	2	0	4½	21
MIZEN-MAST	46	5	0	10	22
Do. top	21	3	0	6	24
Bowsprit	35			14½	29

Extreme breadth 21 f. 2½ in.
Length lower deck 67 4.

Capt. HOULDERSON, Billander, *about* 160 *Tuns.*

	Masts. Length. Feet.	Diam. Inch.	*Yards.* Len. Feet.
MAIN-MAST	68	16½	40
Do. top	68	10	29
FORE-MAST	54	15	38
Do. top	30	9	29
Do. top-gallant	18	5	23
Bowsprit	36	15	
Gibb boom			26

Breadth 21 feet.
Lower deck length 71 f. 4 in.

Capt. ——, 131 *Tuns.*

	Masts. Len. Feet.	Diam. Inches.	*Yards.* Len. Feet.
MAIN-MAST	57	16	40
Do. top	30	9½	30
Do. top.gallant	18	5	23
FORE-MAST	52	15½	35
Do. top	28	9½	28
Do. top-gallant	15	4¾	21
MIZEN-MAST	50	10½	22
Do. top	26	6½	23
Bowsprit	34	16	30
	Crossjack		30

Breadth 21 feet, 2 inches.
Lower deck length 73 f. 3 in.

Capt. ROBIN's, *Snow*, 130 *Tuns.*

	Masts. Len. Feet.	Diam. Inches.	*Yards.* Len. Feet.
MAIN-MAST	56	15	40
Do. top	30	9	30
Do. top-gallant	17		24
FORE-MAST	50	14½	36
Do. top	28	9	28
Do. top-gallant	15		22
Bowsprit	35	15	30

Breadth 21 feet.
Lower deck len. 71 feet, 4 inches.

N. B. The three lower masts were shortened two feet each, and the yards ten inches at each end.

Capt.

Capt. SMITH's *Sloop*, 100 *Tuns.*

	Length Feet.	Diam. In.
Mast	80	19.
Bowsprit	44	15.
Boom	52	12½
Gaph	28	
Spread-yard	40	
Topsail-yard	33	
Crossjack	36	
Top-gallant-mast	19	
Do. yard	28	
Gibb boom	30	
Breadth	20	
Length	61	

Capt. GILBER's *Sloop*, 83 *Tuns.*

	Length Feet.	Diam. In.
Mast	73	17.
Bowsprit	42	14
Boom		50
Spread-yard	37	
Top-sail-yard	26	
Crossjack	33	
Top-gallant-mast	13	
Do. yard	22	
Gibb boom	26	
Breadth	18 f. 9 in	
Length	57 f. 2 in	

Capt. NICKALL's *Sloop*, 51 *Tuns.*

	Length Feet.	Diam. In.
Mast	65	15.
Top-mast	14	
Top-gallant-mast	21	5
Bowsprit	40	11.
Boom	44	
Gaph	24	
Spread-yard	34	
Topsail, Do.	27	
Top-gallant, Do.	26	
Crossjack, Do.	30	
Breadth	16	

Proportions for Masts and Yards in the Royal Navy.

THE masts are proportioned to the extreme breadth of the ship from out to out, and the yards to the length of the gun deck; and as this treatise is chiefly designed for the ship-wrights of his Majesty's dock yards, we shall here give the general proportions of masts and yards, for the benefit of such of them as may be employed at sea.

As to the form of masts and yards, the general method is to quarter the masts from the partners to the hounds, and the yards from the slings to the yard arms; so that both yard arms are exactly the same, except the mizen yard. The diameters at the quarters are in proportion to that at the partners or slings; whether this curve will be an arch of a circle or of an ellipse, or only a fair curve, we shall not at present examine, only give our readers the proportions; but as the beams are allowed to be arches of circles, we shall here shew a ready way of making a beam mould.

Let A B, *Fig.* 73, be the length of the beam, C D the round in the middle, so it is only describing a circle thro' the three points A D B; but as the circle in some cases will be so large that we cannot come at the center we may use the following method.

1*st*. Draw the lines A D and D B.

2*d*. From

2d. From the center D, and with the radius D C, describe a circle; make the arch $a\,e$ equal to the arch C a, and the arch $b\,f$ equal to the arch C b, so the arches $a\,e$, and $b\,f$, will be equal, and of consequence, the angles A D C, A D e, B D C, B D f, will all be equal.

3d. Divide the lines D C, D e, and D f into as many equal parts as you propose to find points in the curve; it is indifferent whether these parts be equal or unequal; only observing to begin the divisions from the point D, and that the divisions of the lines D e, and D f, be the same distance from the point D that their corresponding divisions in the line D C are from the same point.

4th. Draw the line B x to the first division of the line D f, and a line from A, thro' z (the first division of the line D C), to intersect the line B x in g, which will be one point in the curve.

In like manner the other points are found, by drawing lines from B to the several divisions of the line D f, and lines from A thro' the corresponding divisions of the line D C, to intersect those drawn from B, which will all be in the circumference of the circle. In the figure we have only drawn the lines B x, and A g; but, in practice, we may take two chalk lines and fasten one at A and the other at B, and stretching the one thro' the points in the line D C, and the other thro' the corresponding points in the lines D f, and D e, the intersections of the chalk lines will give the several points in the circumference.

DEMONSTRATION.

The angle at the circumference of a circle is measured by half the opposite arch, as demonstrated in page 28. Hence all angles at the circumference of a circle that stand on the same chord are equal, and of consequence, if there be never so many equal angles standing on the same chord, they will be all in the circumference of a circle; or, which is the same thing, a curve drawn thro' the several angular points will be an arch of a circle.

The triangles B D x, and A D z are equal, for the sides A D, and D B are equal, the sides D x, and D z are likewise equal, and the angle B D x included by the sides B D and D x, equal to the angle A D z, included by the sides A D and D z; therefore the angle D B x is equal to the angle D A z.

The angles D A B, and D B A, are equal, and subtracting their sum from 180 we have the angle A D B; but the sum of the angles x B A, and z A B, is equal to the sum of the angles D A B, and D B A, for the angle D B x is added to the angle D B A, and the angle D A z (equal

to

to the angle D B x) is subtracted from the angle D A B; therefore, the angle A b B is equal to the angle A D B, and of consequence the arch of the circle will pass thro' both; the like may be said of all the rest.

Proportions for the length of Masts, Anno 1745.

			Guns
1000 : breadth :: in feet	748 : 756 : 753 : 741 : 740 : 747 : 760 :	main mast in yards	100 90 80 70 and 60 50 44 24
1000 : main mast : :	895 : 901 :	fore-mast	100 90 80 all the rest
1000 : main mast : :	870 : 866 :	mizen-mast	100 90 80 all the rest.
1000 : main mast : :	640 : 613 :	bow-sprit	100 90 80 all the rest
1000 : main mast : :	600 : 605 : 607 :	main-top-mast	100 90 80 70 60 50 40 24
1000 : main-top-mast : :	900 : 910 :	fore-top-mast	100 90 80 all the rest.
1000 : main-top-mast : :	710 : 717 :	mizen-top-mast	100 90 80 all the rest.
1000 : main-top-mast : :	480 : 508 :	main-top gallant mast	100 90 80 all the rest.
1000 : fore top-mast : :	480 : 505 :	fore top-gallant-mast	100 90 80 all the rest.
1000 : bow-sprit : : : :	360	sprit-sail top-mast	100 90 80

Proportions for the length of yards.

			Guns
1000 : gun deck : : :	560 : 559 : 570 : 576 : 575 : 561 :	main yard	100 90 80 70 60 50 24 44
1000 : main yard : :	880 : 874 :	fore yard	100 90 80 all the rest.

1000

1000 : main yard : :	820 :	mizen yard	100 98 80 60 44
	847 :		70
	840 :		24
1000 : main yard : :	726 :	main top sail yard	24
	720 :		all the rest,
1000 : fore yard : :	719 :	fore top-sail-yard	70
	726 :		24
	715 :		all the rest.
1000 : main top sail ya. : :	690 :	main top gall. yard	all the rates
1000 : fore top-sail ya. : :	696 :	fore top gal. ya.	70
	690 :		all the rest.
1000 : fore top-sail ya. : :	768 :	miz. top-sail ya.	70
	750 :		all the rest.

Crofs jack and fprit-fail yards equal to the fore top-fail yard.
Sprit top-fail yard equal to the fore top gallant yard.

Having now found the length of the mafts and yards; our next bufinefs is to determine their diameters at the partners and flings.

Proportions for the Diameters of Mafts and Yards.

The main and fore maft in all fhips down to 60 guns, 1 inch diameter to every yard in length.

For 50 and 40 guns, twenty-feven twenty-eights of an inch diameter, to one yard in length.

For 24 guns, twelve thirteens of an inch diameter to one yard in length.

All top mafts are nine tenths of an inch diameter to one yard in length.

The fore top-maft as big as the main top-maft.

The top gallant maft, one inch to a yard.

The mizen-maft $\frac{15}{22}$ of an inch to 1 yard in length.

The mizen top-maft five fixths of an inch to one yard in length.

The bow-fprit an inch and half to one yard.

The flying gibb-boom feven eighths of a fhip to a yard.

The main and fore yard five fevenths of an inch to a yard.

The top-fail, crofs-jack, and fprit-fail yards nine fourteenths of an inch to one yard.

The top-gallant, mizen top-fail, and fprit-fail top fail yards eight thirteenths of an inch to one yard.

The

The mizen yard five ninths of an inch to one yard.

All ſteering ſail booms and yards half an inch to one yard in length.

Proportions for the diameters, at the quarters of maſts and yards, according to their diameters at the partners, or ſlings.

For the main and fore maſt, firſt quarter $\frac{42}{43}$ parts; ſecond quarter $\frac{14}{15}$ parts; third quarter $\frac{5}{6}$ parts; hounds $\frac{9}{10}$ parts; for the head $\frac{5}{7}$ parts; heel $\frac{5}{6}$ parts.

For the mizen maſt, and ſloops maſts that head themſelves, firſt quarter $\frac{60}{61}$; for the ſecond quarter $\frac{11}{12}$; for the third quarter, a ſtrait line from the ſecond to the hounds; hounds three quarters; for the head two thirds.

For top and top gallant maſts, firſt quarter $\frac{40}{41}$ parts; ſecond quarter $\frac{14}{15}$ parts; third quarter $\frac{5}{6}$ parts; hounds $\frac{9}{10}$ parts; head $\frac{5}{9}$ parts.

For the bow-ſprit, firſt quarter $\frac{30}{31}$ parts; ſecond quarter $\frac{9}{10}$ parts; third quarter 3 quarters; at the cap one half; at the heel 3 quarters.

For yards in general; firſt quarter $\frac{27}{28}$ parts; ſecond quarter nine tenths; third quarter ſeven tenths; yard arm two fifths.

For the lower arm of the mizen yard, firſt quarter $\frac{40}{41}$ parts; ſecond quarter $\frac{12}{13}$ parts; third quarter $\frac{5}{6}$ parts; yard arm two thirds.

The upper arm of the mizen yard the ſame as yards in general.

As ſome of our readers may not be acquainted with the way of notation in theſe proportions, we refer them to what is ſaid on that head in the firſt part, where the principles of the rule of proportion, and the conſtruction of the line of numbers is explained, and the uſe of the ſliding-rule illuſtrated by a great variety of examples in the rule of three.

Thoſe that are but the leaſt acquainted with the rule of three, know that there are three numbers given; and, that if the ſecond be multiplied by the third, and that product divided by the firſt, the quotient will give the fourth term, which will have the ſame proportion to the third, that the ſecond term has to the firſt.

The proportion for the main maſt of a ſhip of 50 guns, is thus expreſſed; 1000 : 740 : : breadth : length, that is to ſay, (ſuppoſing the breadth be 41 feet,): If 1000 give 740, what will 41 give?

Now, in order to give a ſolution to this by the ſliding-rule, draw out the ſlider till 1000 is right againſt 740, and right againſt 41, you'll find 30$\frac{1}{3}$, nearly, which is the length of the main-maſt in yards: It is indifferent whether 1000 be on the ſlider or on the rule; but if 1000 be on the ſlider, 41 the breadth muſt likewiſe be on the ſlider, ſo 740 and $30\frac{1}{3}$, will be on the rule, and the contrary; or univerſally, the firſt and ſecond terms will be on the ſame line of numbers, and the third and fourth on the other line of numbers, and it is indifferent whether 740, or the breadth, be the ſecond term, but 1000 muſt be the firſt; and the length the fourth term; the one upon the ſlider and the other on the rule.

The diameter at the partners you will find in the proportions $\frac{27}{28}$ parts of an inch to every yard in length; that is to ſay, if the maſt were 28 yards long, the diameter at the partners would be 27 inches; and therefore by the rule of three 28 : 27 : : $30\frac{1}{3}$: $29\frac{1}{4}$; therefore, draw out the ſlider till 28 is againſt 27, and right againſt $30\frac{1}{3}$ is $29\frac{1}{4}$.

The diameters at the quarters are given in what the ſhip-wrights call fractional parts of the diameter at the partners, or ſlings; that of the firſt quarter of the main maſt is $\frac{42}{43}$, that is to ſay, if the diameter at the partners be 43, that at the firſt quarter will be 42. Now the diameter at the partners, by the preceding operation, is $30\frac{1}{3}$, ſo we have three terms of the rule of three given, thus expreſſed, 43 : 42 : $30\frac{1}{3}$, and when the ſlider is drawn out till 43 is againſt 42, we ſhall find $29\frac{1}{2}$ againſt $30\frac{1}{3}$, ſo $29\frac{1}{2}$ inches is the diameter at the firſt quarter; hence we have this general rule; when the fractional part is given, draw out the ſlider till the denominator is right againſt the numerator, then look for the diameter at the partners, or ſlings, on the ſame line with the denominator; and right againſt the partners, or ſlings, you have the diameter for that quarter, and by uſing the ſame operation as for finding the firſt quarters, we ſhall find the ſecond quarter $28\frac{1}{4}$; the third $25\frac{1}{4}$; the bound $20\frac{3}{4}$; and at the head $17\frac{1}{4}$.

Now, to find the length and diameter of the main yard; the length of the gun deck is 144 feet, the proportion for the length is 1000 : 575 : : 144, therefore, draw out the ſlider till 1000 is right againſt 575, and right againſt 144 is 83 nearly, which is the length of the main yard in feet.

The diameter at the ſlings is $\frac{5}{7}$ of an inch to every yard in length; 83 feet is $27\frac{2}{3}$ yards, therefore draw out the ſlider till 7 is againſt 5, and againſt $27\frac{2}{3}$ is $19\frac{3}{4}$.

It is preſumed theſe examples may ſuffice to explain the manner of notation in the preceding proportions, and likewiſe the method of working by the ſliding-rule, which may be applied to all queſtions in the rule of three, ſuch as meaſuring plank, and timber, wainſcoting, &c.

We

We ſhall now give our readers the proportions, for the heads, and hounds of maſts, and likewiſe for the caps, tops, truſſel-trees, and croſs-trees.

Proportions for Heads and Hounds of Maſts.

The head of the main and fore maſts, five inches to one yard of the length of the maſt.

Mizen-maſt head, if it ſteps in the hold, $4\frac{1}{8}$ of an inch to one yard in length.

All top and top-gallant maſt heads, four inches to a yard in length.

The length of the hounds, two fifths of their reſpective heads.

Proportions for Caps.

All caps, except the flying gibb boom, to be in breadth twice the diameter of their top-maſts; and their lengths to be twice their breadth. The thickneſs of the main and fore caps, half the diameter of their breadths; the mizen cap three ſevenths, and the top-maſts two fifths of their reſpective breadths.

The flying gibb boom cap, to be in length five times the diameter of the boom, and in breadth twice its diameter, and, in depth, nine tenths of the breadth.

Proportions for Tops.

The breadth of the top thwartſhips, to be one third of the length of the top-maſt; the mizen-top thwartſhips, by ſome, is nine thirtieths of the length of the mizen top-maſt; all tops, before and aſt, three fourths of what they are thwartſhips; the ſquare hole five inches to a foot.

Proportions for Truſſel-trees.

In length, to reach within three inches of the outer edge of the top.

The depth of the main and fore truſſel-trees, $\frac{25}{26}$ of an inch to one foot in length; their breadth five ſevenths of their depth.

The depth of the mizen truſſel-trees, ſix ſevenths of an inch to one foot in length; and their breadth eleven ſixteenths of their depth.

The main and fore top-maſt truſſel-trees, to be in length the fifth part of the length of their top-gallant-maſts; their depths $\frac{25}{26}$ of an inch to one foot in length, and their breadth $\frac{18}{25}$ of their depth.

The mizen-top-maſt truſſel-trees, half the length of the main-top-maſt truſſel-trees; their depth, one inch to a foot in length, and their breadth five ſixths of their depth.

Pro-

Proportions for Croſs-trees.

The length of the croſs-trees, for the main and fore croſs-trees, to reach within three inches of the outer edge of the top.

The mizen croſs-trees, the ſame length with the truſſel-trees.

The croſs-trees the ſame breadth with the truſſel-trees, and half their depth.

Weight of Anchors, and Dimenſions of Cables.

In the merchant ſervice, the ſheet, beſt, and ſmall bower anchors are generally different, but in the navy theſe three are of the ſame weight. The dimenſions of the cables are eſtimated by their circumferences.

ANCHORS.	100 Guns.	90 Guns.	80 Guns.	74 Guns.	64 Guns.	50 Guns.	40 Guns.	32 Guns.	Sloops.
	C. qrs.	C. qrs.	C. qrs.	C. qrs.	C. qrs.	C. qrs.	C. qrs.	C. qrs.	C. qrs.
Bowers	77 0	71 2	66 2	71 2	54 2	44 0	37 3	32 0	15 0
Stream	19 2	17 9	15 2	13 1	13 9	11 9	10 2	8 1	7 0
CABLES.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.
Sheet & bow.	23	22	21	22	$18\frac{1}{2}$	$17\frac{1}{2}$	16	$14\frac{1}{2}$	13
Stream	$14\frac{1}{2}$	$13\frac{1}{2}$	13	$13\frac{1}{2}$	$11\frac{1}{2}$	11	10	$8\frac{1}{2}$	8
Hawſers	$9\frac{1}{2}$	9	$8\frac{1}{2}$	9	8	$7\frac{1}{2}$	$6\frac{1}{2}$	$5\frac{1}{2}$	$4\frac{1}{2}$
ditto	9	$8\frac{1}{2}$	8	$8\frac{1}{2}$	$7\frac{1}{2}$	$6\frac{1}{2}$	$6\frac{1}{2}$	$5\frac{1}{2}$	$4\frac{1}{2}$

A TABLE *of the Number of Guns on each Deck, their Length, Weight of Metal, and Shot.*

Guns	DECKS	Number on each	Length feet	Length in.	Wt. of metal. C wt.	Wt. of ſhot. pounds.
	Lower	28	10	0	67	42
	Middle	28	9	6	49	24
100.	Upper	28	9	6	34	12
	Quarter	12	8	0	22	6
	Fore Caſtle	4	9	0	24	6
	Lower	26	9	6	55	32
	Middle	26	9	6	42	18
90.	Upper	26	9	0	32	12
	Quarter	10	8	0	22	6
	Fore Caſtle	2	9	0	24	6

A TABLE

A TABLE *of the Number of Guns on each Deck, their Length, Weight of Metal, and Shot.*

Guns	Decks	Number on each	Length feet	Length in.	Wt. of metal. Cwt.	Wt. of shot. pounds.
80	Lower	26	9	6	55	32
	Middle	26	9	0	40	18
	Upper	24	9	0	29	9
	Quarter	4	7	6	20$\frac{1}{2}$	6
74	Lower	28	9	6	55	32
	Upper	28	9	0	40	18
	Quarter	16	8	0	26$\frac{1}{2}$	9
	Fore Castle	2	9	0	29	9
64	Lower	26	9	6	55	32
	Upper	26	9	0	40	18
	Quarter	10	7	6	24$\frac{1}{2}$	9
	Fore Castle	2	8	6	27$\frac{1}{2}$	9
60	Lower	24	9	6	49	24
	Upper	24	9	0	32$\frac{1}{2}$	12
	Quarter	8	7	0	20$\frac{1}{2}$	6
	Fore Castle	2	8	6	23	6
50	Lower	22	9	0	47$\frac{1}{2}$	24
	Upper	22	8	6	31	12
	Quarter	4	7	8	18	6
	Fore Castle	2			22	6
44	Lower	20	9	0	40	18
	Upper	20	8	0	26	9
	Quarter	4	6	6	18	
24	Lower	2	7	0	23	9
	Upper	20	7	0	23	9
	Quarter	2	4	6	7$\frac{1}{4}$	3

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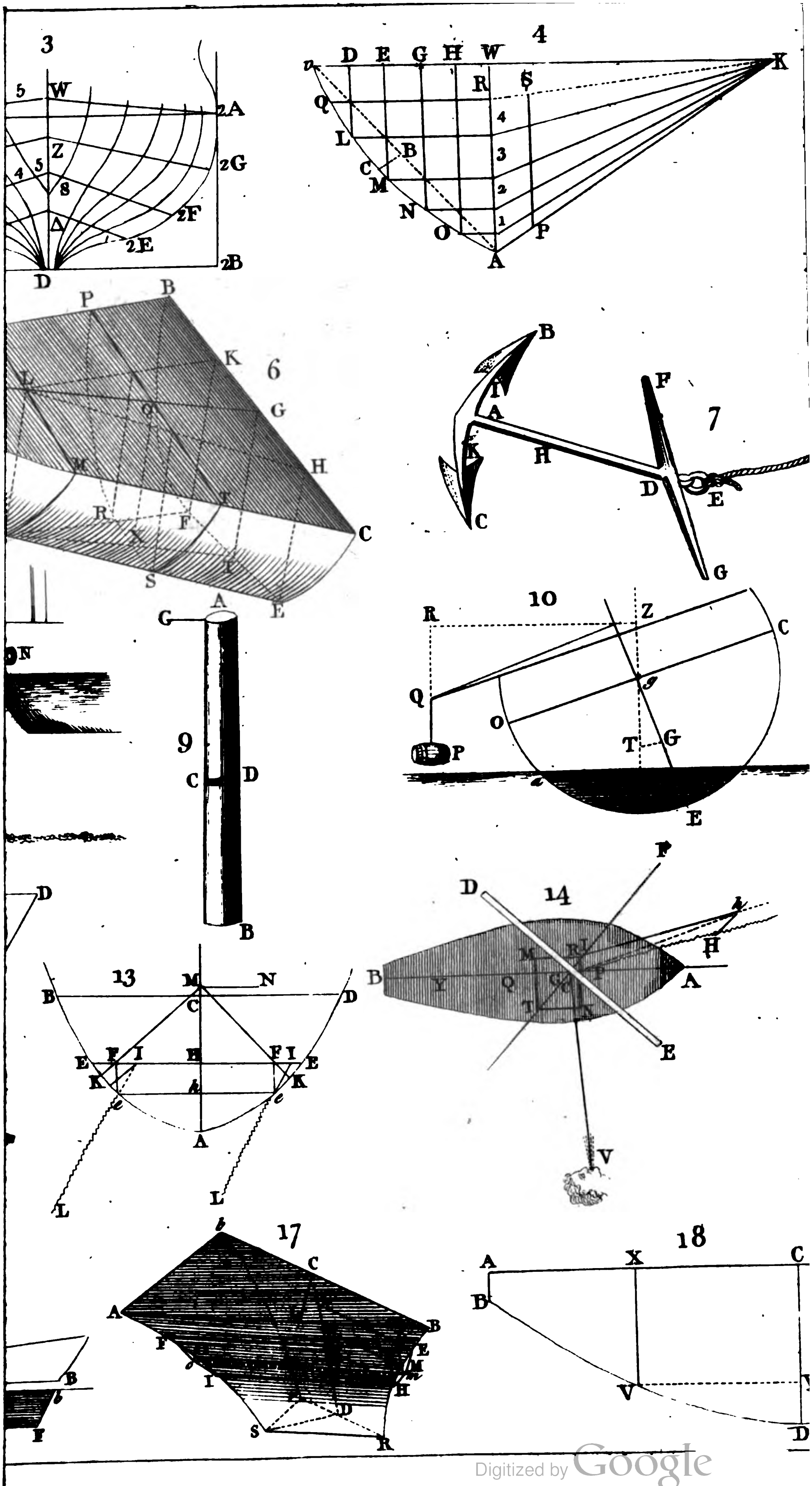
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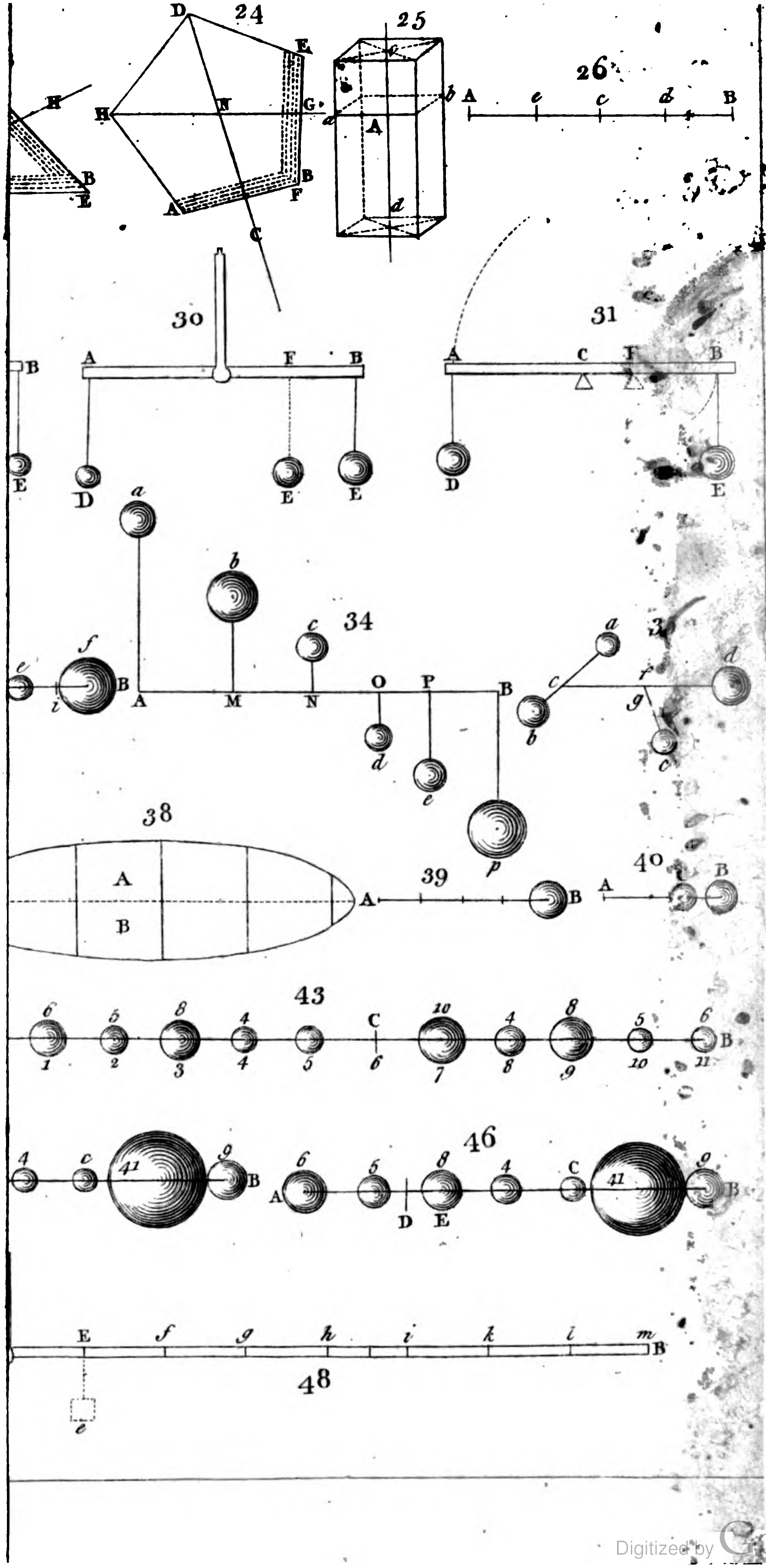

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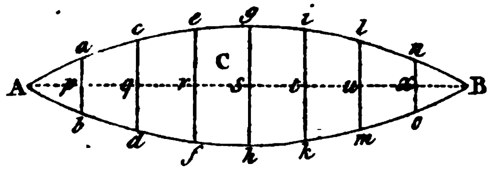

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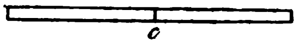

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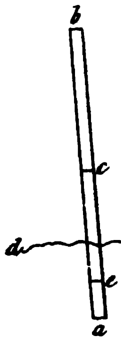

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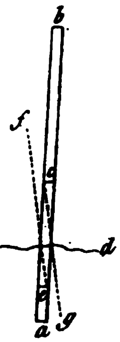

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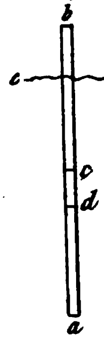

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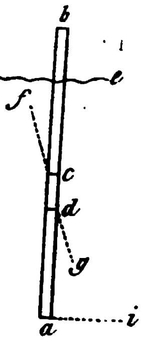

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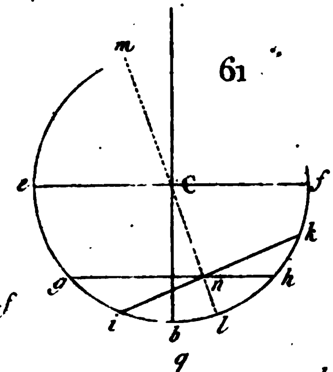

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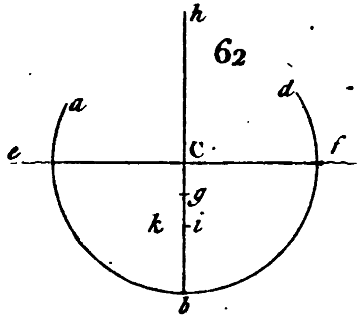

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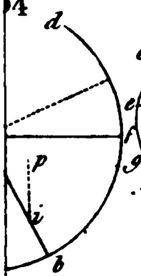

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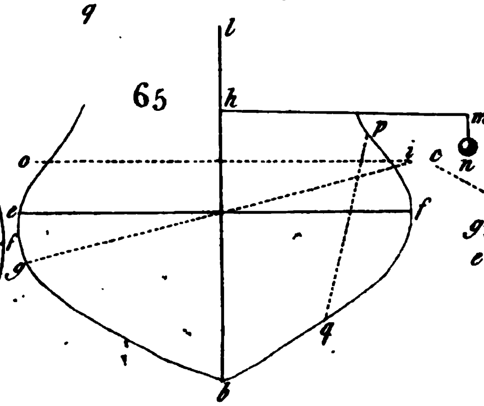

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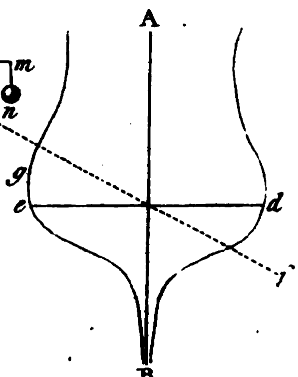

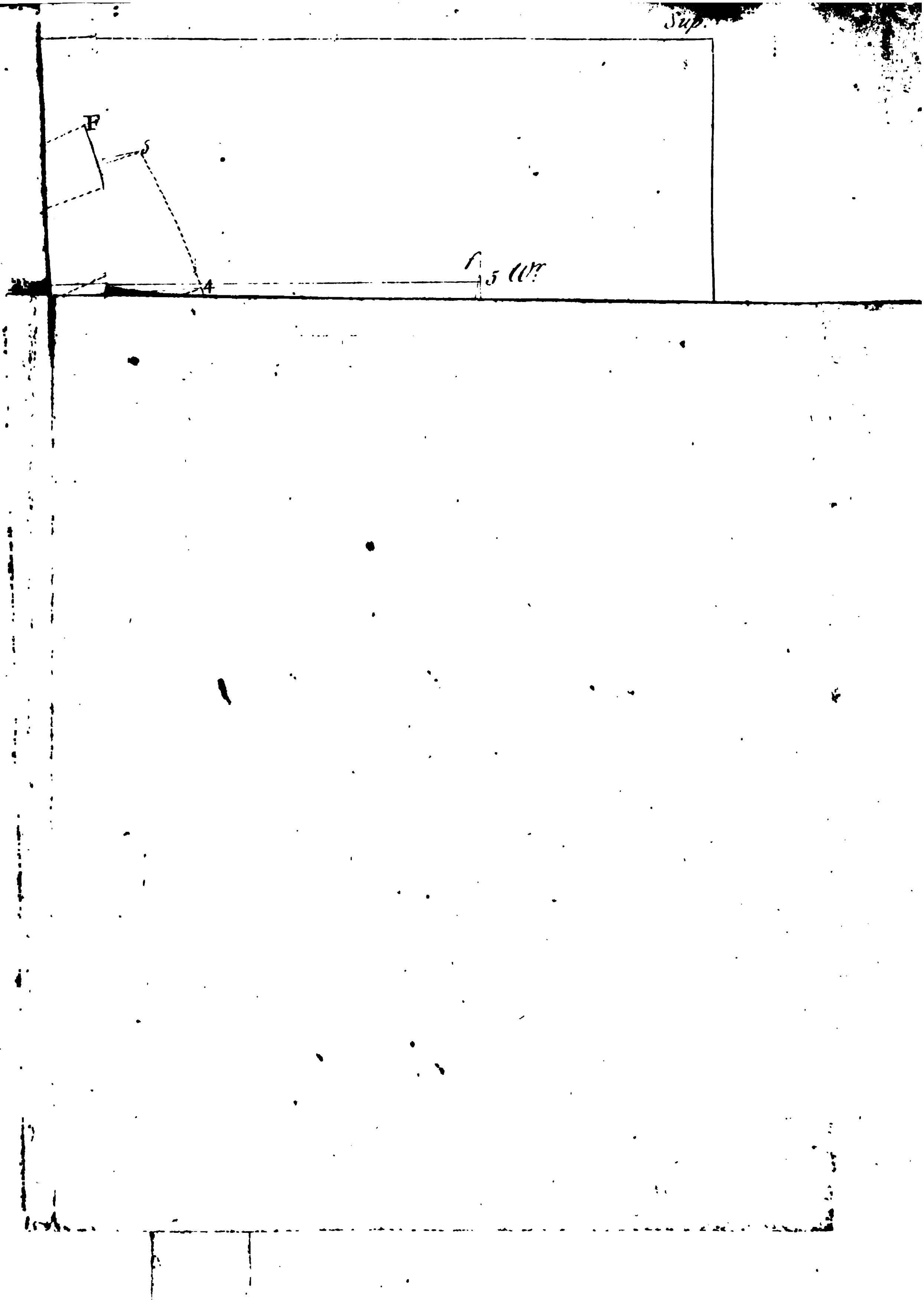
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