Fig. 2.

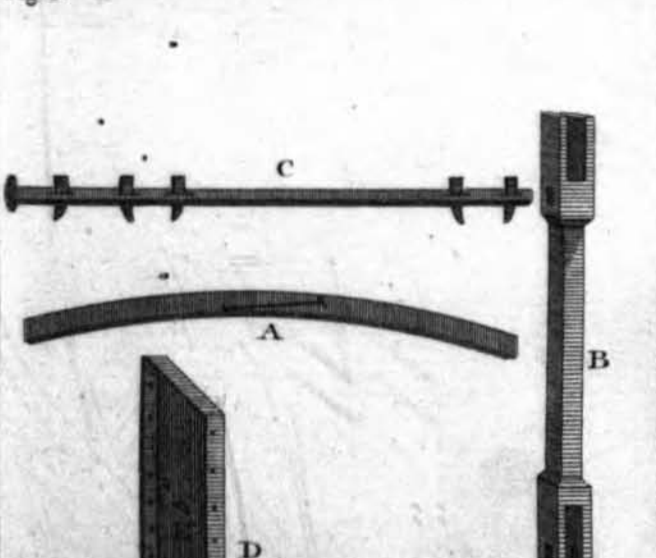
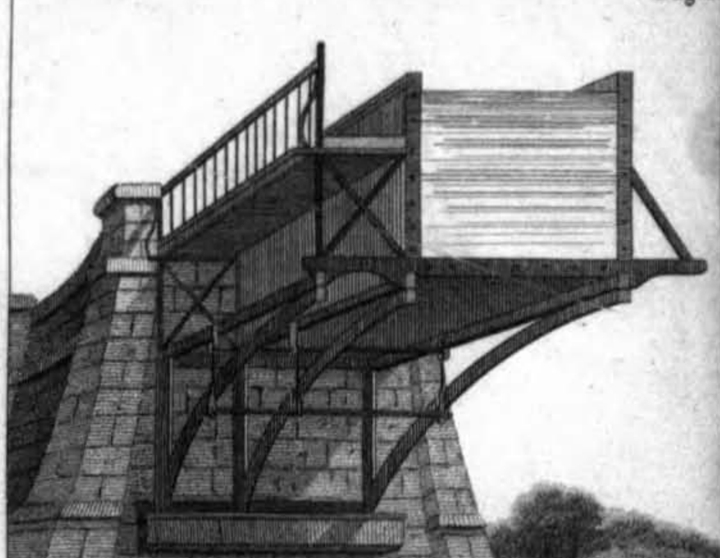



Fig. 1



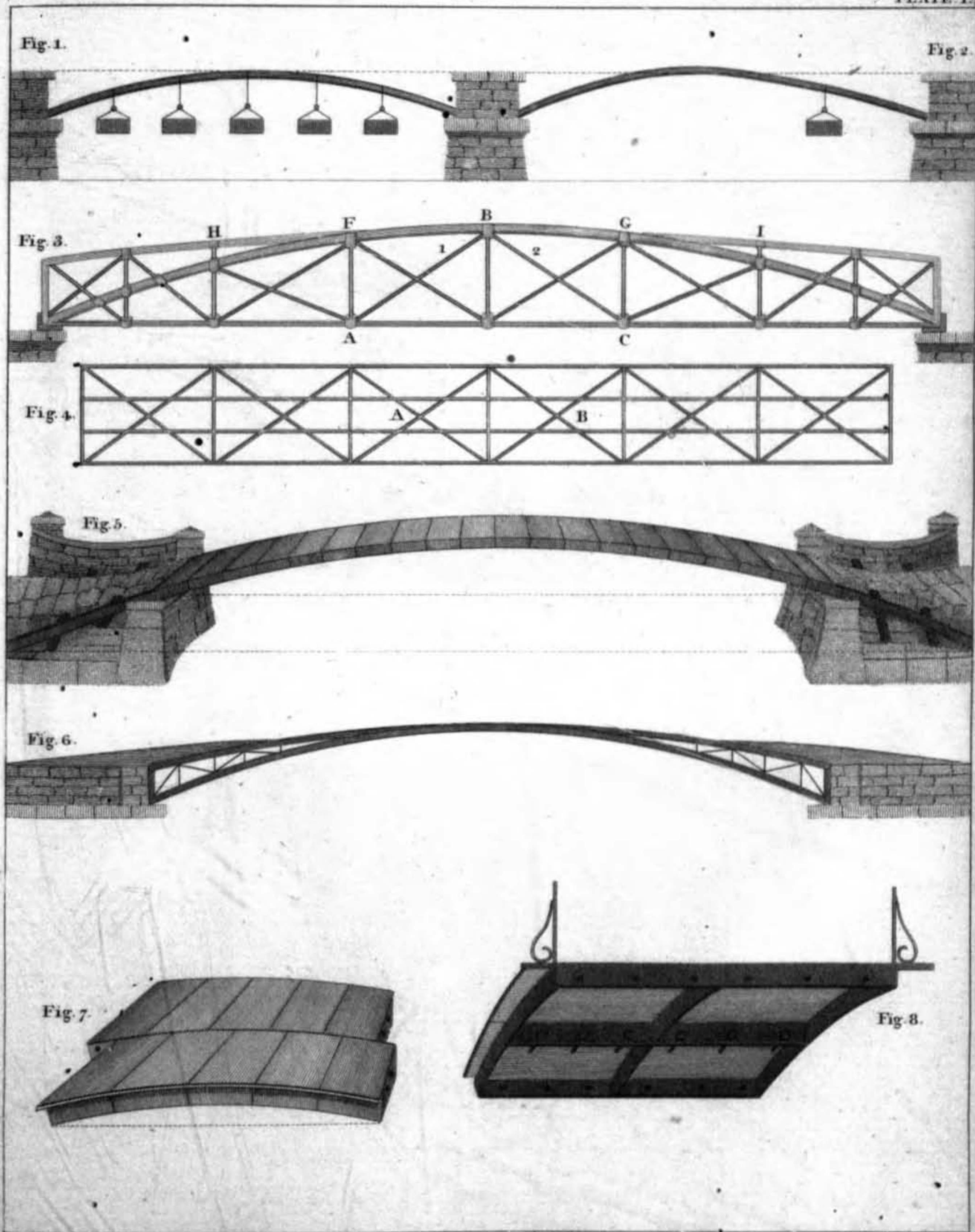
R. Fulton, invent et delin.

*An Iron Aqueduct Scale 1½ Inch to 100 Feet.*

Fig. 1. *Section 1 Inch to 6 Feet.* — Fig. 2. *Parts 1 Inch to 4 Feet.*

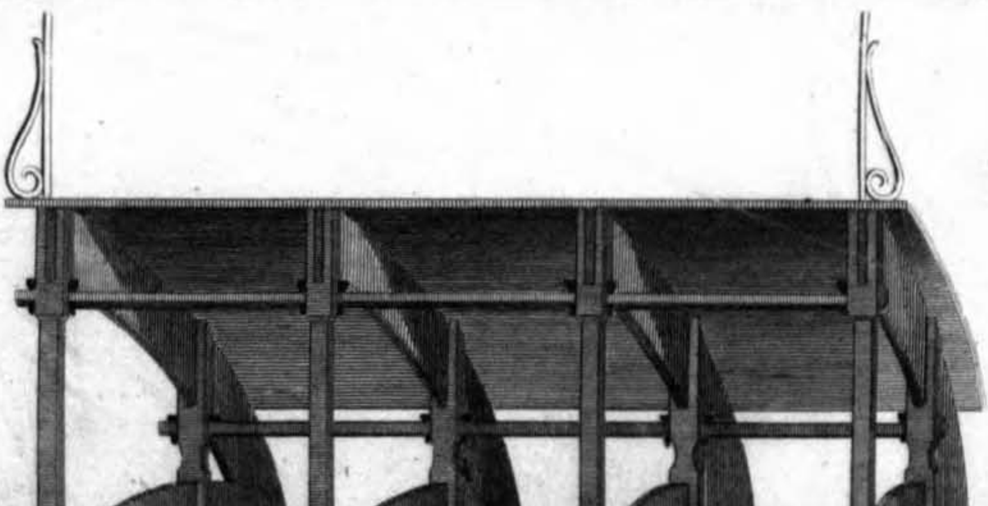
London Published by I. & J. Taylor, Holborn, March 1, 1806.

PLATE 14.




*Parts of Iron Bridges.*

R. Fulton invent et delin.



R. Fulton, invenit et delin.

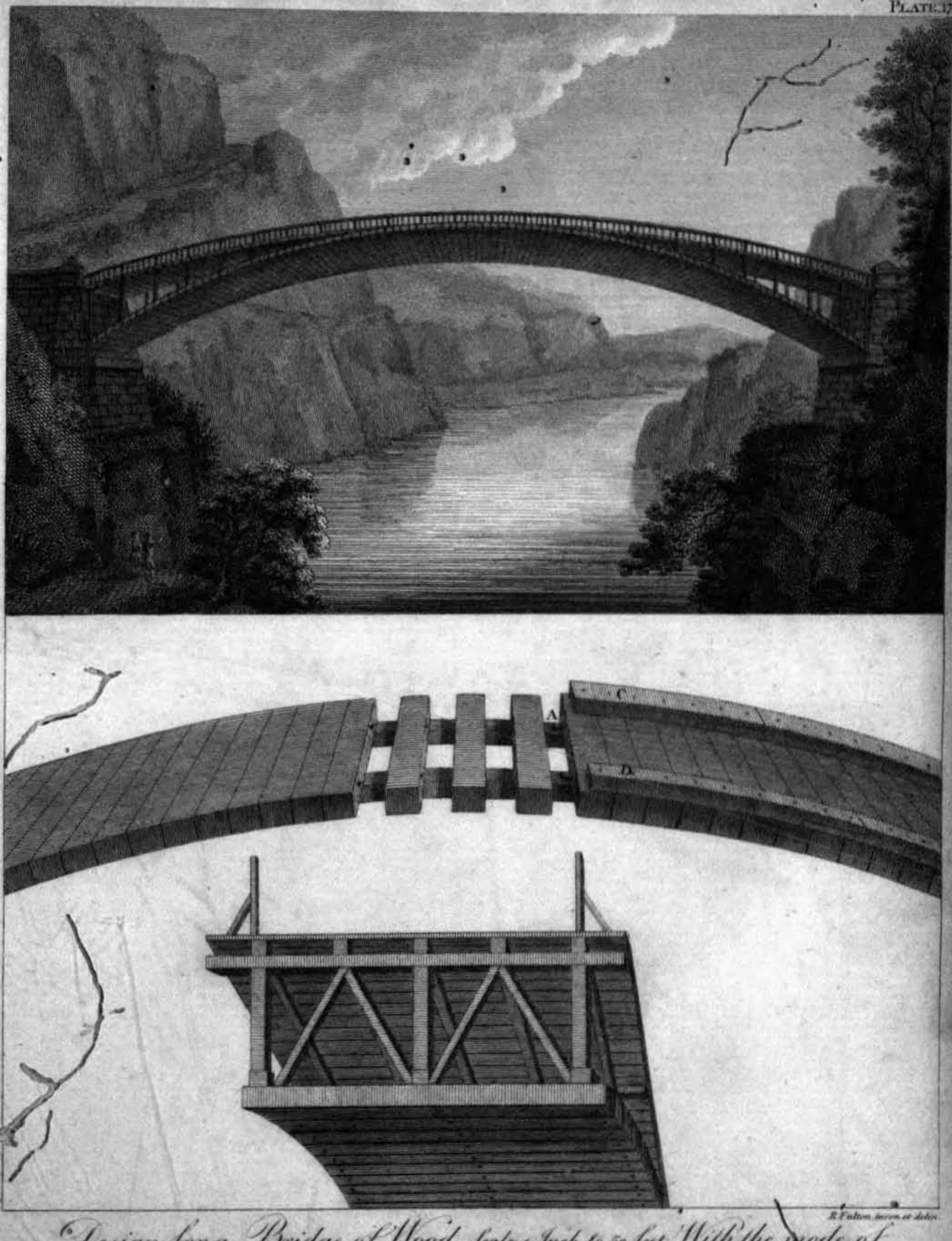
*Design for an Iron Bridge Scale 1 Inch to 10 Feet.*
*The Section Shews the Ribs and Braces Scale 1 Inch to 4 Feet.*

PLATE 16

R. Fulton invent et delin.

Part of a Bridge composed of Iron Staves.

London: Published by I. & J. Taylor, Holborn March 1. 1796.




R. Fulton, invent et delin.

*Design for a Bridge of Wood, Scale 1 Inch to 50 feet, With the mode of Combining the Timbers.*

London, Published by I. & J. Taylor

# OBSERVATIONS

ON

# CANAL NAVIGATION, &c.

# OBSERVATIONS

ON THE

VARIOUS SYSTEMS

OF

# CANAL NAVIGATION,

WITH

INFERENCES PRACTICAL AND MATHEMATICAL;

IN WHICH

## Mr. FULTON'S PLAN

OF

# WHEEL-BOATS,

AND THE UTILITY OF SUBTERRANEOUS AND OF SMALL CANALS
ARE PARTICULARLY INVESTIGATED,

INCLUDING AN ACCOUNT OF THE

## CANALS AND INCLINED PLANES OF CHINA.

WITH FOUR PLATES.

---

*BY WILLIAM CHAPMAN,*

MEMBER OF THE SOCIETY OF CIVIL ENGINEERS IN LONDON, AND M. R. I. A.

---

*LONDON:*

PUBLISHED BY I. AND J. TAYLOR, AT THE ARCHITECTURAL LIBRARY,
HIGH HOLBORN.

1797.

TO

HIS GRACE

# FRANCIS DUKE OF BRIDGEWATER,

THESE OBSERVATIONS ARE INSCRIBED,

AS A MARK OF THE

AUTHOR'S VENERATION

FOR THE

DIGNIFIED CHARACTER,

TO WHOSE GREAT EXAMPLE

THE CANALS OF THESE KINGDOMS

OWE THEIR ORIGIN:

FROM WHICH HAVE RESULTED

MUCH OF

THE COMMERCIAL AND POLITICAL IMPORTANCE

OF THIS

EMPIRE.

*Newcastle-upon-Tyne*, 1797.

# CONTENTS.

## ERRATA.

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28   11, for *becaufe the* read *becaufe of the*.
31   9, for *as to* read *as confiderably to*.
32   10, for *axes* read *axis*.
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38   10, for *giving* read *given*.
39   9, for *l k* read *e k*.
49   6, for *refting power* read *refifting power*.
57   8, from bottom, for *fection* read *fecant*.
62   6, from bottom, for *fnow* read *fnows*.
67   9, for *article* read *vehicle*.
73   12, from bottom, for *tracked* read *tracked againft*.
76   15, for *given* read *giving*; and line 21, for *other* read *over*.

To thefe might be added, feveral fmall typographic errors, which being fufficiently apparent for the reader to correct, are omitted.

OBSER-

# OBSERVATIONS

ON VARIOUS SYSTEMS OF

# CANAL NAVIGATION.

## CHAP. I.

*Introduction.—Description of various Means of overcoming Ascent and Descent in Canals and Rivers.*

SEVERAL ages probably elapsed before the necessities of mankind caused the introduction of highways and bridges; these would be adequate to every purpose, long after they united into nations, and became stationary in their residence; as they would fix themselves in such places where their wants could easily be supplied, or where navigable rivers would afford the means of exchanging the produce of their industry. But, when increase of numbers induced them to settle in less favorable situations, and called forth their bodily and mental exertions; the necessity of reducing the vast charge of distant conveyance of heavy articles, would point out the eligibility, and eventually the means, of obtaining water carriage, in many places where rivers had not admitted it. Thus Canals began their existence, at remote periods, in the populous countries of China and Egypt; and were adopted by the Romans in many parts of their extended empire, and were introduced by them, into this island, in the fenny country east of the river Trent. Those Canals were, necessarily, on long continued levels; and the communications, either between them or to navigable rivers, required land carriage. This inconvenience, during the course of numerous ages, could not fail attracting the attention of ingenious men; and, accordingly, they devised various means of overcoming ascent, both in Rivers and Canals.

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 It,

It, consequently, is an object of importance, to record all such progressive improvements as have come to the knowlege of any individual; and to investigate every new proposition; as, by a fair discussion, many plans may be introduced to the extent they merit, which might otherwise lie dormant through prejudice, or the caution requisite in all great undertakings: and, on the other hand, it may prevent enthusiasm for plausible systems from misleading, and carrying away, their followers beyond what may be useful.

No system can ever be so perfect, as to be unbounded in the propriety of application; and, therefore, the mode of overcoming ascent and descent by Locks, which is, undoubtedly, a noble invention, and almost generally useful, is not without its limits, as to utility. Having conceded this point, which every impartial man must do; I feel myself more at liberty to controvert the opinion thrown out by Mr. Fulton, in his Treatise on the Improvement of Canals, that Locks will in future be found to be ineligible in all cases; and be superseded by some system similar to what he has laid down.

His plan possesses much ingenuity; but, like others, is necessarily limited in the propriety of its application: and the extent of those limits is what I shall endeavour to explain.

Those who adopt any favorite system on practical subjects, without the aid of experience to guide them, are liable to be carried away by the warmth of their imagination; and are led to apprehend they have attained a something of universal application: To this alone I can attribute Mr. Fulton's reprobation of Locks, so useful for facilitating internal Navigation, and which the experience of three * centuries has barely brought to perfection. Previously to the commencement of this period, and down to the present

* The first Lock was supposed to be erected in the year 1488, upon the Brenta nigh Padua. Immediately afterwards the two Canals of Milan, between which there was nearly 34feet fall, were joined by means of 6 Locks. *Traité des Canaux de Navigation, par M. de la Lande.*

time,

time, the communication between different levels interrupted by fall of ground, by cataracts, or by rapids impracticable to haul boats up, or by intervening high land, has been effected various ways.

1ſt. By portage of the articles from one level to another, and carriage of the boat itſelf, as is practiſed in various parts of North America; for inſtance, at the falls of the Mohawk, the portage from that river to Wood Creek, and the falls of the Onandaga; and even in our own iſland at the Iſthmus of Tarbet in the Mull of Cantyre. This mode is alſo practiſed between Tarbet on Loch Lomond, and Arrachar at the head of Loch Long; at the Tarbet of Jura, and at all the other Tarbets in the Iſles and Highlands: the word Tarbet is derived from two Celtic words, implying the drawing or hauling of a boat; it denotes a low narrow neck of land between two ſeparate waters, or two arms of the ſame ſea or lake.

2d. By hauling the empty boats up the rapids when diſcharged of their cargoes; and conveying the latter by land.

3d. By making the rapids themſelves navigable by contraction; and, where neceſſary, affixing machinery to haul up the boats.

4th. By ſtopping the water of a river for a time, and letting it off to occaſion an artificial flood; as is yet practiſed on the Cam and other rivers.

5th. By Ponts aux Rouleaux, or inclined planes, with rollers at ſhort diſtances, over which, by means of a water wheel, the boats are hove up to the ridge ſeparating the two waters (viz. a little above the level of the higheſt), and is launched, or regularly let down, to the pool or level they are proceeding to. The boats in this method could not be very long, becauſe, although, in aſcending or deſcending the inclined plane, they might bear upon many rollers; yet, in the change of poſition from the regular line of aſcent, they muſt obviouſly bear upon one roller, and be liable to ſtrain *.

In

* The ſame inconvenience muſt attend the Chineſe method, which, of late, is ſaid in ſome inſtances to differ only by the intervention of a cradle between the boat and the rollers.

In an anonymous * Treatife, publifhed in Paris in the year 1693, this mode by rollers is particularly defcribed, and faid to have been practifed for fome time in Holland, with much fuccefs; and that there was a conftruction of that kind in the Canal between Amfterdam and Sardam.

6th. The method recommended by Mr. Leach, land furveyor (in his Treatife on Inland Navigation), who lays claim to the invention (in the year 1774), of connecting long continued levels, by inclined planes, which he propofes to be double parallel planes; and furnifhed with rollers, on which caiffons capable of containing water of fuperior weight to a loaded boat were to move alternately up and down. The boats at the bottom level were to float over thefe caiffons, which, in their paffage up or down the planes with the boats upon them, were to be full or empty as the circumftance might require.

The top of this caiffon is horizontal, and furnifhed with rollers, fo that when it arrives at the ridge, or fummit of the inclined plane, penning up the higher water, the boat may from thence be launched into the upper Canal.

7th. The fyftem lately introduced into this kingdom by Mr. William Reynolds of Ketley, viz. that of connecting, as in the preceding inftance, different levels of Canals, of great intervening height, by means of an inclined plane, with two parallel rail-ways; up and down which, by the aid of a rope paffing over a wheel at the head of the plane, boats of 8 tons burthen alternately pafs upon carriages, over which they are floated at each extremity of the fall. The loaded boat (the trade being defcending) draws up a light boat, or occafionally a half laden one. The firft of thefe works was at Ketley in Shropfhire. The carriage downwards was principally coals, and about four hundred tons daily.

ters. According to Magelhaens (as quoted by Belidor, Architect. Hydraul. t. 4. p. 355 & 356) the Chinefe method was to haul the veffels by the power of capftans, or by the immediate effort of 4 or 500 men, up contracted channels where the water ran with great rapidity, and was confined by mafonry. He alfo defcribes the dry inclined planes for fmaller boats.

* *Traité des Moyens de rendre les Rivieres navigable.* This mode is alfo mentioned in Belidor, Architect. Hydraul, tom. 1.

The

The boats were rectangular boxes of 20 feet in length, 6 feet width, and nearly 4 feet height; and one horfe drew fifteen of them, connected to each other by a few links of chain.

The chief difficulty in going from a higher to a lower level, without wafte of water, lay in paffing the ridge, or dam, which retains the water at the end of the upper level. This he overcame two ways.

In the firft method, which he carried into effect about feven years fince, he avoided the afcent from the upper level to the ridge holding up the water, by the means of two parallel Locks at the head of the inclined plane; into one of which the laden boat floated on its carriage; and the light boat, when afcended into the other, was by the admiffion of water floated off. The water confumed in thefe Locks was let into a fide refervoir, and in dry feafons pumped back by a fteam engine to the other level. Mr. Reynolds has great merit in the invention of this method.

The fecond method, as practifed, at the inclined plane below the iron bridge at Brofeley, in Shropfhire, differs from the former in having no Locks, and the boats being drawn upon the ridge by a fteam engine; which alfo occafionally draws up the light boats, without waiting for the laden ones. The boats, as in the other, are floated upon four-wheeled carriages *, which afcend and defcend alternately.

The merit of this invention, or, at leaft, the firft introducing it into practice (which was I believe totally unknown to Mr. Reynolds) is due to the late Mr. Davis Dukart, an Engineer in the Sardinian fervice, who fettled in Ireland, and became engaged in the Tyrone collieries. Thefe collieries are lefs than a mile North of Dungannon, and about three miles from the colliery bafon, at the head of a Canal afcending by eight Locks

* A leading feature of difference of effect between thefe two methods, is, that the former is applicable to fteeper defcents and longer boats; becaufe the frame of the carriage may at its defcending end be elevated from the inclined plane to any extent; which if done fo confiderably, in the latter method, would dip the oppofite end of the boat in coming in or going out of the upper Canal.

from

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from

from the river Blackwater, near its junction with Lough Neagh. The rise from the bason to the colliery, was little short of 200 feet; and after attempting, very improperly for the particular instance, to conquer this great ascent in that short space, by continuing the Lock Navigation; and finding the sums granted by Government for that purpose inadequate to the design; he turned his attention to small boats, and inclined planes, of which he constructed three, connected by narrow Canals. The falls were seventy, sixty, and fifty-five feet, which last terminated about 15 feet above the colliery bason; from which by a short railway, his boats, again floating over a carriage, were drawn onwards to the wharf, where the railway was supported on geers, or frames, and the boats were turned over to discharge their cargoes. They were calculated to carry, each, a ton of the measure the coals were sold by, viz. (about 27 cwt.) which they did at less than 18 inches draught, so that his Canal might be every where fordable; and, accordingly, no bridges were erected on it.

The boats were flat bottomed, and upright at the sides and ends: their width was $4\frac{1}{2}$ feet, their height 2 feet 6 inches, and 10 feet straight side: one end was square, and the other pointed, so as to form a right angle at the stem; and they went, as in all similar cases, a number of them chained after each other.

His first attempt differed from the "Ponts aux Rouleaux" in no other respect than having a double passage down his inclined planes; so that, by means of a rope leading over a wheel, his loaded boats drew up his light ones:—but finding various inconveniences from some of the rollers not turning, and from the individual inequality of the diameters of others throwing his boats to one side, as well as from other causes; he suggested and put in use, the method now practised on the banks of the Severn, of having a cradle or frame with four wheels, brought under his boats; upon which, over a double railway, they alternately ascended; the sole difference between the two methods being in the size of his boats; and that, in place of a steam engine, he made use of a horse gin to draw his boats upon the ridge terminating the upper level.

This

This work was executed a little prior to the year 1777; but, excepting in paſſing a few boats by way of trial, nothing more was done, as Mr. Dukart could not obtain money to complete ſome of the intervening levels, and died ſoon after the time mentioned. The works were then entirely laid aſide; and, a few years ſince, a common rail road, cutting off a conſiderable portion of the diſtance, has with propriety been adopted in their ſtead.

8th. The method ſuggeſted by the Earl of Stanhope in 1793, viz. the connecting different levels of Canal by iron rail-roads of a gradual and eaſy aſcent; up and down which ſmall boats were to paſs ſuſpended between a pair of wheels of about 6 feet diameter.

9th. The following invention, which is likewiſe aſcribed to his Lordſhip, viz. the paſſing of boats, up or down an inclined plane, on rollers moving with the boats for half their length, in which ſpace the boats would paſs over them. The rollers are then to return to their places; by means of weights acting over pulleys, and connected by a chain to the ends of each roller. This method, undoubtedly, would be attended with conſiderable expence in the execution; but has the merit of getting quit of the friction of rollers moving on gudgeons. It muſt however poſſeſs the other inconveniences of the " Ponts aux Rouleaux." The moſt material of theſe are that the boats muſt reſt on a ſingle roller in the convex part of the road; unleſs all convexity be avoided by having a lock at the head of the inclined plane; in which caſe the aſcent muſt be very gentle or the boat be ſhort, or high at the ends, to enable her to float from her reclined poſition. If the way be very ſteep, a frame for the boat to reſt on, and raiſed at the lower end, would be requiſite.

A method of uſing moving rollers attached to ſuch a frame has been ſuggeſted by Mr. Fulton. He propoſes to connect them, by the gudgeons at their ends paſſing through an endleſs chain, or collar, and thus returning the rollers over the frame, but under the boat.

By

By the former method, the frame, or boat, muſt frequently reſt only on two rollers; but in this they may be as cloſe to each other as requiſite: and by having in place of one ſet, a ſet of rollers on each ſide, this method (with a regular declivity of plane and locks at the head of it) is capable of being carried into effect for boats of any magnitude ſuitable for paſſing on inclined planes.

10th. The method publiſhed by Dr. Anderſon of Edinburgh, in "The General View of the Agriculture and Rural Œconomy of the County of Aberdeen, for the year 1794."

The Doctor, there, obſerves that, for all the purpoſes of commerce, no more width of boat is requiſite than four feet; or more than two or three feet depth; and that the length might be indefinite ſo as not to be inconvenient for aſcending and deſcending between any two levels of Canal; which he propoſes to be done in the following manner, viz. that the lower level be run up to nearly under the end of the upper, and terminate by an upright end, and two ſide walls of maſonry, to the full height of the fall; with a pier in the middle, dividing the paſſage between the two ſide walls, into two openings of rather greater width than the boat: the two ends of this pier are to be elevated ſo as to ſuſtain the axis of a wheel of a diameter equal to the width of the pier, and half of each opening. A chain paſſing over the wheel, ſuſpends, from each end, a rectangular caſe ſo hung that when one ſhall be at the bottom ready for a boat to float into; the other ſhall be at the top, and cloſe preſſed to the wall or frame at the end of the Canal, ſo as to prevent the eſcape of water: then, by opening a ſtop-gate at the end of either Canal, and another at the correſponding end of the caſe, it is obvious that the boat may float in or out. The lower boat and caſe (or caſe with water only) are then in a kind of Lock, juſt containing the caſe, and of ſufficient depth to permit it to deſcend to the level of the lower Canal. From this Lock there is a conduit to keep the water down below the Canal bottom.

Theſe are the outlines of the invention; which, where the connection between the two levels is a precipice, or ſo ſteep as to require only a ſhort tunnel

tunnel to the well, or pit, up or down which the boats are to move, may, on receiving fuch improvements as it is capable of, be eafily carried into effect for fmall boats; for which alone the author propofes it.

It is obvious that, under other circumftances as to fituation, the expences of high embankments above, of deep finking below, and of bringing up the conduit to lay dry the lower locks, muft more than counterbalance any advantage that can be derived from it.

11th. Meffrs. Rowland and Pickering's plan of enabling great boats to afcend and defcend with inconfiderable wafte of water. This confifts in having, at the head of the lower level of Canal, a pit funk as much below the bottom of it, as the difference of height between the two levels, added to the depth of a covered caiffon of requifite magnitude. This caiffon, when immerfed in the water, with which the pit is filled to the level of the bottom of the Canal, is to fupport, on wooden or iron pillars of height equal to the fall between the two levels, or trough or cradle, with gates or draw doors at each end; containing a fufficient depth of water, to which the floating power of the caiffon muft then be in equilibrio; and, confequently, capable of moving with eafe between the top and bottom of the pit.

When the furface of the water of the cradle is level with either of the Canals, and the end of it clofed againft the framing of the gate of the Canal, by fcrews, or other means; and the water let in to fill the vacancy between the gate of the cradle and that of the Canal, they both may then be opened, and a boat be admitted, or pafs out.

Excepting what may, if neceffary, be ufed for regulating the equipoife and change of motion; the intermediate water between the gate of each level and that of the cradle, is all that is confumed; and with draw doors to the cradle and fingle gates to each level, as already premifed, the quantity muft be very trivial. The weight of water difplaced by the bulk of the pillars fuftaining the cradle, need not be material; and, where requifite, it is propofed to be counterbalanced by weights acting on a fpiral wheel.

This plan, which poſſeſſes ingenuity, and is applicable in many inſtances, is now carried into execution on the Elleſmere Canal, near Ruabon in Denbighſhire; on a fall of 12 feet, and for boats of 70 feet length, and ſeven feet width; and the whole is moved up and down by a rack and pinion towards each end of the machine.

Meſſrs. Rowland and Pickering's invention alſo extends to another principle; that of counterbalancing the cradle containing the boat by weight; which, if carried to the perfection it is capable of, will in high falls have decided advantages.

12th. Mr. Weldon's Caiſſon Lock, or Diving Cheſt, in which boats with their cargoes are to deſcend, to a conſiderable depth, down a pit or well; and afterwards paſs by a tunnel into a lower Canal: and to aſcend in a ſimilar manner.

This method is now carrying into effect on the Somerſetſhire Coal Canal at Moncton Comb near Bath, on a fall of about 45 feet, and for boats of 72 feet length, and ſeven feet width.

The caiſſon, or cheſt, is cylindric; and, in this inſtance, of ſufficient ſtrength to bear the preſſure of a column of water 54 feet, or upwards; to which it is ſubjected, when oppoſite the lower level, on account of the neceſſity of its being covered when oppoſed to the entrance of the upper level. It is ſo balanced that when it has ſufficient water within it to float a boat, it is of the ſame ſpecific gravity as the medium it floats in: and, like an air balloon, it aſcends or deſcends by a ſlight increaſe, or diminution of its relative gravity; which, in this machine, is done by raiſing out, or admitting an inconſiderable quantity of water. The pit, in which the diving cheſt moves, has, oppoſite each level of Canal, a tunnel or opening cloſed with gates; and is ſo much higher than the upper Canal as to contain a height of water juſt ſufficient, as already mentioned, to cover the caiſſon when oppoſite the upper level. In this, or in its lower poſition, when run cloſe to, and abutting againſt, the entrance, it is retained by the water being let out of the ſhort part of the tunnel between the gates of the level, and the end

end of the caiſſon. It is then held there by the preſſure of the column of water intervening between the ſurface of the pit and that of the Canal to which it is oppoſed. The gates of the level and Canal are then opened, and the boat goes in or out; and, on the gates being again cloſed, and the water let into the vacancy, the diving cheſt is ready to proceed to the other level.

This ſcheme poſſeſſes much originality, and may often be uſefully applied. It and the preceding one are ſecured to their reſpective inventors by patents; therefore I ſhall refrain from giving my ſentiments on the ſeparate advantages of each, and from pointing out the inſtances in which either might have the preference of the other. In general, all methods of aſcending and deſcending which ſave water, where the want of it for other purpoſes, whether for giving motion to machinery, or the irrigation of land, would be greater than the advantage the navigation would obtain by the uſe of it, muſt clearly be ſo far beneficial to the community.

13th. The laſt method * introduced to the public, is the one which has principally occaſioned this Eſſay, viz. Mr. Fulton's wheel boats; which, when applied to inclined planes, he looks upon as paramount to all other modes. The novelty of this method conſiſts principally in having † wheels affixed to, or underneath, his boats; and in the deſcending and aſcending boats each keeping their proper track; and not moving alternately in oppoſite directions, as in the method practiſed at Dungannon and Coalbrook Dale, and as recommended by Mr. Leach and Dr. Anderſon. His boats, he obſerves, may be of a rectangular form, and from 2 to 4 ‡ feet wide. Thoſe of the latter width which he particularly deſcribes, he recommends to be 20 feet long, and 2 feet 10 inches deep; and propoſes

* A Treatiſe on the Improvement of Canal Navigation, exhibiting the numerous advantages to be derived from ſmall Canals. 4to, with 17 plates, 1796.

† They are more properly tracks, viz. wheels between whoſe diameter, and that of their axis, there is little diſparity, and conſequently their friction great; as alſo is their inability to ſurmount any caſual obſtacle.

‡ In the title page he ſays 2 to 5 feet.

them to carry four tons each. He ſays they may be " compoſed of 3 inch " deal, bolted and ſcrewed in the uſual mode, and ſtayed at the corners, " with two knees or ribs inſide, exactly above the wheels, and about 5 " feet from the ends, which will leave 10 feet in the centre." Under the boat's bottom, he propoſes two pair of wheels of from 6 to 10 inches diameter; the axle and pair of wheels to be of one piece, and turn on braſs or iron collars. Each pair of wheels are to tread only two feet, ſo as to be perfectly clear of the ſides of the Canal: and, to prevent any impediment from their axle-trees, they are to be caſed over with thin plank, forming a falſe bottom from one axis to the other. A boat ſuch as deſcribed will (excluſive of the frame under the bottom, which I ſhall admit to float the wheels) be equal to a ſolid maſs of fir timber of the length and width of the boat, and 8 inches in depth; and, allowing for the iron work, will draw at leaſt 6 inches when light, excluſive of the wheels; and with 4 tons bare weight (allowing in round numbers 36 cubic feet of water to be a ton) will draw 2 feet $3\frac{1}{2}$ inches.

Theſe boats then with wheels ſix inches below their bottoms, will draw 2 feet 9 inches water: and as there ſhould always be 2 or 3 inches to ſpare, their draught will be too great for * fords; therefore bridges cannot be diſpenſed with. He propoſes, very properly, that the canal ſhould be every where wide enough for boats to paſs each other; which, of courſe, will be 3 or 4 feet more than their joint width of bottom; as, otherwiſe, the ſides of the Canal would be cut down by their ſharp angles; which, even then, cannot be effectually avoided.

* The fords ſhould be all paved; and if the boats in going over them ſhould touch, their wheels would help them on; but it would not be adviſeable, as one horſe ſhould draw ſeveral boats, to ſubmit to that inconvenience.

A ſix-inch wheel I look upon as of ar too ſmall a diameter; but as, by ſpiking a piece of board immediately over the wheels, they may be let nearly or quite through the bottom, and a larger diameter be admitted; I ſhall only add 6 inches below the bottom, which ſpace is requiſite to prevent the neceſſary curveture of the extremities of the railway touching the boat.

The

The depth below the water line, cannot, with propriety, be lefs than 3 feet 6 inches, to make proper allowance for filting up: and 9 feet width of bottom, is the leaft it can be, to admit of the free paffage of thefe upright fided boats.

Thefe dimenfions are below what Mr. Fulton has informed me he propofed: and I have purpofely affumed them to fhew that the comparifon, in the next chapter, is not calculated to depreciate the fyftem he has brought forward.

CHAP.

## CHAP. II.

*On the comparative Expence of forming narrow Canals with inclined Planes, and wide Canals with Locks; ſtating alſo their reſpective Advantages; and comparing the Conſumption of Water by Mr. Fulton's Plan, with what is requiſite for Locks.*

AS the great diſparity of expence is a leading argument, with Mr. Fulton, againſt the Lock Syſtem of Navigation; I ſhall, before I proceed, ſhew how far that ſyſtem ought to be followed, or rejected, for the one he has recommended; and endeavour to prove, that in general inſtances, the diſparity of expence is not nearly ſo great as he has ſtated. For this purpoſe, I will compare his plan with a navigation for 50 to 60 ton boats, of 60 or 70 feet length, 14 feet width, and 4 feet 6 or 4 feet 9 inches draught of water; a ſuitable Canal for which would be of 24 feet width of bottom, and 6 feet depth of water; which would afford room, every where, for two boats to paſs, as their ſection would not be angular, but curved. The diagrams 1, 2, 3, 4, and 1, 5, 6, 7, *figure* I. *plate* I. (admitting the ſlopes to be what they moſt generally are, viz. 18 inches baſe for every foot in height), will ſhew the profile of each Canal, at what is termed level cutting, viz. where the level of the ground is equal to the ſurface of the water.

The ſecond comparative diagrams, viz. *a*, *b*, *c*, 2, 3, *d*, *e*, *f*, and *a*, *b*, *c*, 5, 6, *g*, *h*, *k*, ſhew what they will be at 5 feet extraordinary ſinking; allowing, at 2 feet above the water, 9 feet offset on the towing path ſide; and a berm of 3 feet on the other, to prevent earth tumbling into the Canal. The diagrams 8, 9 and 8, 10 in the ſame figure, ſhew 10 feet extra ſinking.

Theſe diagrams will be more or leſs near the truth, according to the tenacity of the ſoil, and other circumſtances; but I have taken them at the

the general run of the foils of the navigations of this country; which, although when firft cut, they will ftand fteeper, will generally crumble down to 16 or 18 inches bafe, to a foot in height; at which flope, loofe foil will ftand when not agitated by water.

The fucceeding comparative diagrams, in *figure* 2, *plate* I, fhew the embankments of one fide of each Canal, where the furface of the ground is $2\frac{1}{2}$ feet, 6 feet, and 10 feet under the furface of the water. The line *a b* is the middle of the fmall canal, and *d e* that of the greater, allowing them to continue of the fame width as where their channels have to be excavated. They are generally wider in embankment, particularly in thofe of fmall height; which, fo far, would operate againft the fmall canals.

Thefe feven pofitions of comparifon are what will commonly occur, exclufive of greater difficulties (which will ftill more equalize the fyftems) and for that caufe I have affumed them.

At a given diftance from the fummits of mountains towards the low grounds of the valleys, a regular tract may be found, where, without much curvature, a line of level cutting may be uninterruptedly carried.

The falls, in thefe countries, are confequently great; and minerals the almoft fole articles of carriage.

The fides of the mountains are alfo frequently too fteep, and the foil too fhallow, to admit of wide Canals without great expence; therefore, under thefe predicaments, inclined planes and fmall boats are moft eligible: but, on the general elevations through which lines of Canal run, the country is often croffed tranfverfely to the courfe of the fmaller rivers; and the furface of the ground neceffarily undulates; fo that no continued line of level finking can be obtained, without immenfe * circuity, viz. without curving

* According to Mr. Leach's account (in Page 47, of the 2d edition of his works) the diftance from Bude Haven, in the Briftol Channel, to the navigable part of the Tamer falling into the Englifh Channel, is no more than 28 miles in a direct line: but, by the courfe neceffary to be taken in the feveral intervening valleys in order to preferve the level, the line was extended to upwards of 80 miles.

to the brow of every ſwelling point of land, and returning up every vale, until the proper level be regained; which, in itſelf, is ſo obviouſly abſurd, that no further reaſoning is requiſite to ſhew the neceſſity of frequently incurring a fluctuation of more than 10 feet above and below the line. I ſpeak not of the vales of great rivers, which I allow may be paſſed by inclined planes, deſcending to the valley and riſing on the oppoſite ſide: but were this to be done on every ravine that is to be paſſed, the inconvenience would be great indeed: and, therefore, many embankments muſt occur far beyond what I have ſtated; and I ſhall now proceed to their comparative examination.

| | | 4 *Ton Canal.* | 60 *Ton Canal.* |
|---|---|---|---|
| In the firſt ſtatement, or level cutting, the comparative ſections and conſequently the quantity of earth are, | | 50 | 198 |
| At the depth of | 5 feet extra ſinking, - - - | 221 | 482 |
| At | 10 feet do. - - - - - | 491 | 864 |
| Surface of ground | 2 feet 6 inches under water line, - | 107 | 107 |
| Do. | 6 feet do. - - - - | 287 | 287 |
| Do. | 10 feet do. - - - - | 577 | 583 |

From whence it follows, that under the firſt predicament of level cutting, the quantity of the ſmall Canal is ſcarcely more than † one fourth of the greater: that, in the ſecond inſtance, it advances to more than four ninths; and, in the third, to nearly four ſevenths; ſtill approaching nearer as the cutting becomes deeper. And as the embankment, when even ſo trivial as 2 feet 6 inches, and thence downwards to above 6 feet, is equal in

* The banks are eſtimated at only 10 feet width each; and one foot mean height above the ſurface of the water; and without allowance for ſubſidence.

† If no puddling to keep in the water were requiſite the expence would be leſs than a quarter; becauſe the whole might be caſt out: but as the puddling (which in the leſſer Canal would be twice as coſtly as the excavation) would be nearly as the ſurface of the ſides and bottom, the diſparity would be ſo far reduced in what may require puddling, that the general proportion of expence may ſtand as the quantity of excavation, or even higher.

both

both Canals; at 10 feet nearly the ſame; and, afterwards, not eſſentially in favour of the ſmall ones, until the embankments become very high: it may fairly be concluded, that in the common run of navigable lines, ſuch as deſcribed, the expence of cutting the Canal for four-ton boats would be half that of a Canal for 50 or 60 tons.

2d. The expence of fencing and gravelling the track-way will be the ſame in both.

3d. The next expence I ſhall conſider is the land, the quantity of which will be preciſely the ſame as to the towing paths, the ſlopes of the banks above water, and the outward ſlope of the embankments; the ſole ſaving being in the reduction of the water line: and taking the average in a favourable ſtatement for the ſmall canal, the land required will be three fifths of the larger.

4th. Brooks muſt be paſſed under the * ſmall canal in common with the large ones; and as the expence of the ends of the culverts would be equal in both caſes; the only ſaving, unleſs ſome excavation under low embankments, would be in their difference of length, which, in the higher embankments, would be only the difference of the width of water, viz. 22½ feet; and, under low embankments, where the culvert would require to be as high as the depth of water in the ſhallow Canal would admit, the ſaving in length would be 30 feet, viz. the difference of width of water added to the reduction of the width of the embankment on the level of the culvert. If, in this inſtance, the culvert under the deep Canal be either ſyphon formed, or raiſed at the upſtream end, the diſparity of length would be leſs; but the difference of excavation in favour of the ſmall Canal has

* Dr. Anderſon propoſes to ſave the expence of moſt of the culverts, by bringing the leſſer rivulets into his ſmall Canals, and paſſing them over paved overflows oppoſite to the inlets; but this ſcheme, beſides inevitably filling his Canal with ſand and gravel, would in great floods render it impaſſable, and overflow the regular height of the banks; and alſo would never be agreed to by thoſe poſſeſſing mill property on the ſtreams into which theſe brooks flow.



alſo

alſo to be taken into account. The ſaving, upon an average, will be nearly one third; and, aſſuming it as ſuch, the expence of culverts under the ſmall Canal will be two-thirds of what would be required under the other.

5th. The next point of conſideration is bridges, which, in common with the others, will require towing paths; and, therefore, ought not to be leſs than 10 feet ſpan, and muſt be of ſufficient height to let the horſes paſs under. A boat of 14 feet beam (viz. 10 feet wider than the ſmall ones) will require a bridge of 20 or 21 feet ſpan. The wing walls, and towing paths, will be common to them both; and the foundation and parapets being taken into account, the bridge will, in the ſmaller inſtance, average about four-fifths of the greater; but as a reduction in height will diminiſh the thickneſs of the walls, the whole expence may come to about one half.

6th. In the general run of countries, ſuch as I have deſcribed, the fall is often ſo extremely progreſſive that, even where water is in ſuch abundance as to induce the parties to build double locks wherever the fall admits, they are frequently neceſſitated to build locks of moderate fall, to avoid a long embankment on the one hand, and a continuation of deep cutting on the other. Under this predicament, they would be equally conſtrained to have inclined planes of ſmall fall, with all the apparatus that would be requiſite for great ones. The ſaving, therefore, could not be more than one third; but, on an * average, I ſuppoſe it would be fully one half; and under theſe premiſes, and the ſuppoſition of the ſame average of

* In ſituations properly circumſtanced for ſmall Canals and inclined planes of great fall, I will admit the diſparity to be four to one in favour of the former, as to aſcent and deſcent. I am friendly to the uſe, and only controvert the abuſe of the ſyſtem.

proportionate

proportionate expence in paſſing valleys, I will now proceed to a ſummary of the general compariſon.

| | | *General proportion.* | |
|---|---|---|---|
| | *Fractional proportion.* | *4 Ton Canal.* | *60 Ton Canal.* |
| 1ſt. Cutting, viz. Sinking and embanking, - | $\frac{1}{2}$ | 1 | 2 |
| 2d. Fencing and gravelling the trackways, - | 0 | 1 | 1 |
| 3d. Land, - - - - | $\frac{3}{5}$ | 3 | 5 |
| 4th. Culverts, &c. - - - | $\frac{2}{3}$ | 2 | 3 |
| 5th. Bridges, - - - | $\frac{1}{2}$ | 1 | 2 |
| 6th. Deſcent and aſcent, - - - | $\frac{1}{2}$ | 1 | 2 |

From theſe deductions * it follows the ſavings in ſuch inſtances as I have premiſed, will be very conſiderably leſs than one half by adopting the Navigation, deſcribed by Mr. Fulton, for four-ton boats, in place of thoſe of 60 tons. I will call the ſaving two-fifths; and then proceed to examine what muſt be ſacrificed for that acquiſition.

1ſt. The carriage, in a very conſiderable degree, of all articles that will take damage by being wet †: becauſe the narrow boats of 20 feet length, reſting

* In tunnels through hills the ſaving would generally be about three-fourths; but this is not taken into account, becauſe, where any conſiderable portion of a Navigation muſt be ſubterraneous, that circumſtance will demand ſome reduction of width, accordant with the extent of it, the difficulty of execution, and the objects of purſuit.

† Under this deſcription muſt be included grain, the chief produce of the land; the eaſier diſpoſal of which forms the general inducement for landed proprietors to encourage Canals. From this cauſe, and the creation of demand for internal products of the earth that might otherwiſe lie dormant, and from the conveyance of lime for manure to parts that could not otherwiſe eaſily obtain it, the landed intereſt receives more benefit from internal Navigation than the adventurers who incur the charge of the works, and run the riſque of their failure of reaſonable ſucceſs; which although dubious to the latter, can never be ſo to the land-owner; as, by means of Canals, diſtant and unfavourable ſituations come under regular

refting on two tranfverfe lines over the wheels, would, with heavy cargoes, be very liable to ftrain, fo as to become leaky: and admitting they had a raifed ceiling, which they muft have for the carriage of dry goods, the water from the change of pofition of the boat, on afcending and defcending the inclined planes, will run to the extremities, and be dafhed about fo as to damage the goods; unlefs the ceiling were raifed at the ends, fo as greatly to reduce the ftowage of the boats.

2d. When boats, on the different levels, are committed to the care of different men, it will be impoffible to fix under whofe charge the damage happened, unlefs it became a rule to examine the boats at every place of change of men, which would be attended with too much delay.

3d. From the fame caufes, and the boats having no decks, it will be difficult to prevent pilferage of liquors and fmall articles.

4th. Whenever the wind blew ftrong, the boats would be liable to take in water over their gunwales, notwithftanding their tarpaulins, unlefs they were battoned and nailed down as in fhips hatchways: and, in every crofs reach, the ftring of boats would blow afhore without a man to every boat to keep them off, which would be far too expenfive. At Ketley, they had rails projecting into the Canal, on the convex points, to keep the boats in their regular courfe, which enabled them to go forward in moderate weather; but to navigate, in any ftrength of wind, they would, if even they had rails all the way, require the aid of men to enable boats that were going oppofite ways to pafs each other. Or, otherwife, they muft track their boats with fuch fpeed as to keep them off the fhore, and confequently have very few to a horfe.

regular cultivation, and advance of rents far beyond what could otherwife be given. The frequent oppofition from that quarter, and the fupport that fuch oppofition meets with, clearly fhew, that gentlemen of landed intereft do not in general fee this advantage in the light in which I have defcribed it: the fame oppofition, I am informed, exifted on the firft introduction of turnpike roads, the value of which has now been fufficiently experienced; and the fuperior advantages of Canals cannot fail being foon as generally known.

In

In moderate weather, it would be difficult for a horſe to drag a line of them 200 feet long, viz. 10 boats as propoſed by Mr. Fulton. The ſection of water oppoſed is but ſmall; but the form of the ends of the veſſels is that which gives the greateſt reſiſtance; and they are often repeated, which muſt produce a conſiderable effect, although one veſſel follows in the wake of another. Further cauſes of reſiſtance will ariſe from the line of boats frequently forming a zigzag, and from their vaſt ſurface expoſed to the water. The whole of the effects combined are not reduceable to calculation, and muſt depend on experience.

5th. Packs of hemp and wool, bales of cotton, ſacks of hops, crates of earthen ware and of glaſs, oak bark, bavins, &c. &c. would lie too high, ſo as to overturn the boats, unleſs iron, lead, blocks of tin, or other ponderous articles, were carried at the ſame time; without which, theſe boats would not carry half their tonnage of light goods in any package; the Staffordſhire ſquare-ſectioned boats of ſeven feet width, will ſeldom ſtow, without becoming top heavy, more than two-fifths of the weight they can carry, at a leſs proportionate depth than the boats in queſtion muſt be loaded to, to carry four tons.

In addition to the articles already mentioned, theſe boats cannot carry either long or crooked timber; the former, if of fir, may be floated: but the latter, if of heavy wood, will ſink, and cannot eaſily be managed. Neither would theſe boats be very ſuitable for the conveyance of quick-lime, nor would they carry (becauſe of their ſoon overturning) nearly their tonnage of wheat in ſacks, and ſtill leſs of rye, barley, oats and malt: I, however, do not mean to infer that they will not carry theſe latter articles at all; but only that the quantities will be leſs, nearly in the ratio of their ſpecific gravities; which deficiency in tonnage may, in ſome inſtances, be compenſated by reduction of toll. This width of boat is, however, what cannot be recommended for general purpoſes.

The broad boats of 14 feet will nearly carry their full tonnage of light goods, which circumſtance ariſes from two cauſes: the one is their form (as well as their width) which occaſions their metacentre, or point below which

which the joint weight of boat and cargo may lie without overturning, to be higher than in the other boats *; and the other is, that they are funk, when laden, to a much lefs proportion of their width: befides which, when their draught of water is indefinite (as will further appear from the next chapter) the quantity of light articles that can be carried by boats of different widths, but of fimilar form and length, will be as the fquares of their widths; therefore, a boat of four feet width, in place of carrying half as much as a fimilar one of eight feet, will only carry a fourth, although of the fame length; and but a ninth of one of twelve feet width.

6th. The transfhipping of articles removes the refponfibility; and, as boats are frequently wanted to navigate both canals and rivers, which cannot be done by the fmall boats, that degree of refponfibility muft be loft, and the charge and delay of transfhipping be incurred.

7th. The faving in point of reduction of Canal dues, would not, in articles of merchandize, be equivalent to the inconveniences defcribed.

Having now mentioned my objections to the univerfality of the fyftem recommended by Mr. Fulton, I fhall proceed to notice the cafes wherein I think it eligible, the fteps I think neceffary to its perfection, and the means of "harmonizing the fyftem of internal navigation;" which will not confift in the annihilation of Lock Canals as he has ventured to prognofticate, but in rendering the modes of conveyance in them all, as far as poffible, confonant to each other. Previous to this, I fhall make fome obfervations on the confumption of water. In Locks there is this inconvenience, that, whether the boats afcend or defcend, be light or laden, they confume, on an average, a Lock-full of water; for, although in going downwards, they fave a quantity equal to the weight of the boat and cargo if laden, or of the boat alone if light, in confequence of the bulk of the immerfed part

* Canoes, ufed on the American and other rivers, becaufe of the curved form of their tranfverfe fection, carry their lading higher than fquare-fectioned boats of fimilar width, and are therefore capable of conveying large hogfheads of tobacco, or of other articles, with fafety.

of

of the boat being expelled from the chamber, on the boat's entering from the upper level; this is perfectly counterbalanced by the reverse taking place in the ascending boats, on their quitting the chamber to enter the upper level; consequently, exclusive of leakage, which in well fitted gates is very inconsiderable, we may estimate a boat to consume a lockful in passing any extent to or from the summit. Wherever water is scarce, it is common not to exceed eight feet falls, and to have no double Locks. The next consideration is the depth of water in the Canal; for the greater the depth, the tonnage, contained in any given width and length of boat, will be the more increased.

I will assume the depth of Canal I have heretofore compared the small ones with, viz. 6 feet, which will allow of boats of upwards of 4 feet 8 inches draught. These boats, when light, need not draw so much as 15 or 16 inches water, which will allow 3 feet 4 inches to be sunk by the cargo. If the boats and locks be proportioned to each other, as in all cases of want of water they ought to be, the area of that portion of their height should be at least equal to three-fourths of the area of an equal height of the Lock; consequently, in this instance, 2 feet 6 inches height of the Lock (viz. three-fourths of 3 feet 4 inches), will be equal to the weight of the cargo. Therefore, in a fall of 8 feet, the consumption of water would only be $3\frac{1}{5}$ times the weight of the articles that would be passed, up or down, in place of the disproportion he * speaks of, viz. 133 tons of water for passing 25 tons of goods, instead of 80 † tons (which, as above stated, should produce that effect).

Where the descending trade does not bring up the ascending, he supposes that, by his own system, the weight of water consumed will be ‡ twice

* Vide Fulton, page 69.

† The above clearly relates to a passage only one way; but, if a boat pass a summit, the consumption of water will be twice as much; unless another boat pass down with the same lockful the former rose with. And if boats pass and repass a summit, laden one way only, the water requisite would be nearly 13 times the weight of the goods conveyed: but these extreme circumstances are never permitted to take place wherever water is scarce.

‡ In some instances much more. Vide Fulton, page 79.

that

that of the tonnage. And every valley he passes, by the double inclined plane (described in chapter xi.) descending on one side of the valley, and rising on the other to that or any other level will, of course, repeat the preceding consumption, so that the waste of water may become as considerable as by the Lock system, particularly if the method invented by Mr. Dubie, in the last century, and described by * Belidor, be put in practice, as may, in some few cases, be eligible, viz. the drawing off the upper half of the height of the Lock into a side reservoir, and the remainder into the lower level; so that, in refilling the Lock, the lower half may be filled from the reservoir, and † half only be drawn from the pond, or level above. Or, nearly the whole water may be saved by the Locks described in the 11th and 12th articles of the preceding chapter.

Mr. Fulton has stated seven minutes as requisite in the passing a Lock, which in some instances is the case; but, where sufficient water way is given to the sluices, and expeditious means of opening them adopted, a large Lock may be filled or emptied in two minutes, and a boat passed through (inclusive of the filling) in three minutes, which degree of expedition is requisite wherever passage boats are an object.

* Architect. Hydraul. t. 4, p. 412.

† This may often be eligible in Locks of two or more falls, as a reservoir may be given to each. The subdivision of height of a chamber, may be extended to three or more, so as to reduce the quantity still further; but it would be counteracted by the increase of expence, and the delay in passing the Lock: neither will the saving be quite in the proportion of the number of the reservoirs, because of the fluctuation of the level of their surface, which will be more or less according to their proportionate magnitudes. The method taken by Mr. Dubie, in a Lock of 20 feet fall, on the Canal of Ypres, was to have three divisions for admission of the water.

# CHAP. III.

*Cafes where the fmall Syftem of Navigation is eligible---with fome Propofals for its Improvement.*

THE fyftem of fmall Canals is particularly eligible in all countries where limeftone, coal, iron ore, lead, and other ponderous articles not liable to damage from being wet, or likely to be ftolen, are the objects chiefly to be attended to; and where the regular declivity of the country runs tranfverfely to the courfe of the Canal: which will generally be the cafe along the fides of mountains, at an elevation above the irregular ground at their feet.

In thofe fituations, the great falls, or inclined planes, may be made at the forks of rivers; fo that the upper levels may branch up both the vales, and thus give the moft extended communication. A fituation fuited for thofe canals will often alfo be found in countries that are not abfolutely mountainous, but where the ground regularly declines towards the vales of large rivers.

Bridges, whether of high roads, or of communication between divided property, form an effential article of expence, and may be confiderably avoided in the fmall fyftem. The only thing militating againft it, in the wheel boats, is the great projection of their wheels below the bottom, which renders fords impracticable. The fords ought not to exceed two feet nine inches depth; as, otherwife, hay, fheaves of corn, &c. in common carts, would be liable to get wet. The depth might always be nearly uniform, from the fords being paved, and overflows immediately adjoining, which, to allow for cafual fluctuation, might be fixed at two feet fix inches above the pavement of the fords: then, in place of communication-bridges, it would only be neceffary to form a paved road obliquely down the bank on one fide, croffing the Canal in the fame direction, and floping up the opposite bank. In country roads, wherever the steepness of the ground does not prevent, the descent and ascent may be more rectangular to the line of Canal, or in the direction of the road itself: in which case, the water would extend eight or ten yards on each side, to admit of a proper slope to the road. In great high roads it would be requisite to have bridges. It, consequently, becomes an object of consideration to reduce their expence by having no towing-paths under them; and at the same time not to interrupt the regular tracking of the boats. This end may be effected by a mode somewhat similar to what is used to pass small vessels through one of the bridges at Rotterdam, without either striking their masts or interrupting the foot passengers; which is done by raising and turning back a small leaf in the centre of the bridge of about a foot or eighteen inches opening, which opening the passengers step over, and the vessels mast passes through it. The mode I advise, differs only in there being no necessity for a central leaf; as the bridge may consist of two abutments, just so far asunder as to afford room enough for the boats to pass, and of two permanent leaves properly supported, with an inch and a half opening between the edges of them, guarded with rounded iron. This opening would be no impediment to the road, and through it the rope (properly guided by a leading piece of wood or iron) would pass without interruption. If the Canal be designed for heavy articles only, viz. for the use of particular collieries, limeworks, or mines; then, these bridges would be of little charge *, as they might be low—but if passage-boats be in contemplation, the requisite height would be such, and also some increase of width †, that the saving would be inconsiderable; and it would, in most such instances, be better to build bridges with towing paths over great

* They would cost little more than paved fords, and not limit the boats to so small a draught of water; therefore, unless considerable height above water be wanted, or considerable width, paved fords are not eligible; and where they are not used, the wheel-boats may have the axle-trees of their wheels under their bottoms, and a cavity or channel be left for the upper part of each wheel to turn in, which will simplify the proposed construction of the boat, as calculated for fords.

† These boats ought not to be less than five feet to admit of passengers sitting opposite to each other conveniently; and as the section of their bottoms might be curved, they would as easily pass each other as the square boats of four feet width.

roads,

roads, where they could ill be dispensed with; and where, if fords were admitted, the frequency of passage would interrupt the trade of the Canal. These Canals undoubtedly admit of passage and market boats to descend or ascend the inclined planes, the usual way on carriages, with an advantage in expedition beyond what can be had where many Locks interrupt; which circumstance counterbalances, in those boats, the inconvenience arising from their smallness. This species of Canal, also, obviously admits of rafts * of fir timber being conveyed, as described by Mr. Fulton; but it must be admitted, that they, as well as the sharp-angled boats, will rapidly tear down the banks of the Canal, so as to fill up the bottom and require frequent repairs. From what has been said, it becomes an object to decrease the draught of the boats, so that they shall not draw more with their wheels than two feet four inches; and, also, that the diameter of the wheels should be a little increased, both to avoid excess of friction, and to overcome easier any obstacle arising either from gravel, pieces of stone, or any other impediment, lying casually on the railway, or from the junction of each piece of rail. It is likewise requisite, that the boats, to avoid straining, be shorter †; and, to prevent their too easily overturning with almost any thing but minerals, that they be somewhat broader. These purposes will all be answered by a trivial alteration of their form, which I shall proceed to describe, after premising that I propose their width to be not less than four feet six inches.

* Rafts of timber are permitted to pass on the Canal from the Forth to the *Clyde*; and frequently consist of 70 tons and upwards, composed of five tiers of timber crossed with deals between each; but, in many Canals, they are prohibited on account of the damage they do by cutting the banks with their angles, and the difficulty of steering them; the first of these inconveniencies may be done away by inclosing the lowest tier with two side pieces (each composed of one breadth and a half of fir balk) nearly of the slope of the bank, but rather rounded; and with similar ends, curved inwards for about three feet, taking care that none of the next or immediately subsequent tiers project beyond it. The steerage may be managed by the track-rope being fastened towards the rear end of the raft, and connected with the middle of the fore end of it by another rope, or a small luff-tackle, which a man upon the raft may haul in or let out at pleasure, so as to steer it as effectually as a boat by its rudder.

† This also will be wanted for a purpose hereinafter mentioned.

1ſt. I propoſe their wheels to be 12 or 14 inches diameter, and only to project two inches below the bottom. Theſe wheels muſt, neceſſarily, be ſheltered by the ſides, not only to avoid ſtriking againſt the banks, but that the boats may not entangle with each other.—(*Vide Plate II*).

This purpoſe might have been effected by means more ſimple than ſhewn in the plan, &c. were it not for the neceſſity of attending to the vertical curvature of the railway, which will project upwards, alternately, between the wheels, or towards the ends of the boats. The part of the boat below the wheel's axis, although contracted 6 inches in width, on each ſide, as *fig.* 3, will not only add conſiderably to the burthen, but afford the means of preſerving the cargo from being injured by leakage: becauſe the ceiling of the boat being neceſſarily raiſed above the thwart timbers, and a conſiderable ſpace left between the ceiling and bottom plank.

2d. The increaſed width of the boat from 4 feet to 4 feet 6 inches, will add both to the burthen and ſtability of the boat, without any ſenſible difference of expence in the Canal, as one foot more width, which requires only a vertical ſection of that width, will afford the neceſſary increaſe of ſpace to allow the boats to paſs each other, and the increaſe of excavation of the Canal is comparatively nothing, becauſe the ſides are common to all widths of the ſame depth; from which cauſe, excepting where ſubterraneous navigation is requiſite, there are no ſufficient advantages ariſing from a very limited width; and, even under that predicament, if there be any material length of carriage, either under ground, or ſubſequently, it will be eligible to keep, at leaſt, to the width I have mentioned.

The boats in the Duke of Bridgewater's works at Worſley, where there are ſubterraneous Canals on different levels, are of this width. There are ſome caſes in ſhort ſubterraneous Canals where 4 feet or leſs width of boat may anſwer the purpoſe. It may be frequently ſo with iron, or other ores, and ſometimes with coals, when ſent forward in the ſmall corves or boxes, in which they are brought from the face of the mine; as, in this inſtance, the boat would only be laden to a ſmall depth, and the cargo not lie ſo high as to endanger its overturning.

3d. If

| | Feet. | Inches. |
|---|---|---|
| 3d. If the boats be from 3 to 4 times as long as they are broad, their draught of water, when light, may be - | 0 | 8 |
| Projection of wheels below their bottom - | 0 | 2 |
| Depth to be ſunk by their loading - | 1 | 6 |
| Total | 2 | 4 |

at which draught I have before ſtated, they may navigate over the fords without danger of impediment.

Under the above predicaments, every 5 feet 4 inches length of boat will carry a ton; therefore, 4 tons may be carried in one of 21 feet 4 inches length, and 3 tons in one of 16 feet; which latter ſize, as being leſs liable to ſtrain when reſting on its wheels, and for other cauſes will, in general, have ſuperior advantages.

In boats laden with coals, lime, iron ore, or other minerals, it will evidently be a great convenience to empty them with equal facility as a waggon; which, particularly in ſhort boats, may be effected in the two following ways: the boats, in both inſtances, having their ends ceiled, with a ſlope of about 18 inches baſe to a foot in height. The Canal (in the firſt method that I ſhall deſcribe) ſhould terminate above, and near to, the place of diſcharge, which, in this inſtance, I will ſuppoſe to be a coal ſtaith. At the end of the Canal there may be a dock juſt containimg a ſet of boats (which will be hereafter deſcribed) or a gently aſcending railway; in the latter caſe the boat may eaſily be drawn out, by a horſe acting on a two-fold purchaſe, viz. by a rope attached to a poſt cloſe to the ſide of the railway, and above the head of the ſlope, which rope being paſſed through a block hooked to the head of the boat, and returning to a horſe harneſſed to it, upon the railway, will give power ſufficient to raiſe the boat out, in the ſpace of 10 yards; the firſt part of the aſcent being ſteep, on account of the boat being waterborne.

If a dock be uſed, the waſte of water will be ſmall, as there will be no deſcent of the boat; and the only difference will be, that the boats will be more eaſily run forward over the frame-way of the ſtaith. When arrived

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If a dock be uſed, the waſte of water will be ſmall, as there will be no deſcent of the boat; and the only difference will be, that the boats will be more eaſily run forward over the frame-way of the ſtaith. When arrived at any place of difcharge (whether upon the ftaith, or into veffels lying below) the boat will have to run upon a frame fufpended on two gudgeons at half its length, a little below the centre of gravity of the loaded, and above that of the light boat; the frame (being fo contrived that the boat on taking its pofition, becomes fecured in its place) will then readily be turned up to fuch * pofition as will permit the contents of the boat to fhoot out, and will, afterwards, be as readily turned back again, from the pofition of the centre occafioning it to preponderate each way alternately.

Where the coals, or other minerals, are not wanted to be occafionally lodged in a ftaith, but to be only turned over into larger veffels, on a greater navigation; a method practifed in a part of South Wales, with fmall boats bringing iron ore from a drift out of the mine, may be made ufe of. It confifts in continuing the Canal (which may be a wooden trough) to the place of difcharge, and terminating it on a caiffon, fufpended on a tranfverfe centre. The boat being arrived in its place, the end of the Canal is clofed by a ftop-gate; and the fmall quantity of water contained in the caiffon, which the boat fhould as nearly as may be fill, being let out, the cafe, or frame, with the boat in it, may be turned over as already defcribed.

In the former method (which will be more generally ufeful) the boats will, occafionally, have to fhoot their cargoes, in different places, on a coal ftaith, or quay, and confequently will have to turn; therefore, boats of 16 feet length, which I have already faid will carry 3 tons each, cannot conveniently be made ufe of; that circumftance may render it eligible, in many inftances, to have them fhorter, and of lefs burthen; which, according to the fyftem I fhall proceed to lay down, will be attended with no difadvantage of moment.

* The turning of the frame muft be limited to the extent of this pofition, which, with the end flope of the boat's ceiling, already mentioned, will be fufficient at little more than 70° from the plane of the horizon. The fides of the frame fhould fit clofe to the boat's gunwale, and rife fufficiently above it, to prevent the matter it contains from running over its fides when rufhing out of the boat.

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I have already mentioned the extreme difficulty of managing a train of boats, when the wind blows ſtrong; and alſo the great reſiſtance to their paſſage through the water from the form of their ends, as well as the damage done to the banks from the angles of the boats, which principally * ariſes from the corners plowing up the banks. To remedy this, for any great extent, by any thing placed along the banks of the Canal, would be worſe than the diſeaſe; ſome other mode muſt therefore be adopted.

The way, that occurs to me, is to conſtruct and connect the boats, in ſuch a manner as to avoid cutting the banks, and likewiſe enable them to go ſufficiently faſt through the water, ſo as to be capable of ſteering, and not to be driven by the wind on either bank, and, at the ſame time, retain the power of being ſent down the inclined planes without being ſeparated.

Two, three, or more boats, according to their length and the ſuddenneſs of the curvature of the Canal, may be firmly connected, one cloſe behind the other, ſo as to form one boat; and, by having a ſlight overhanging at the end of each, they will, when on their wheels, bend to the convexity of the upper part of the railway, and being faſtened near the gunwale at each angle on either end, there is no impediment to their equally ſuiting the concavity of the lower part. The boats, thus connected, would ſtill oppoſe great reſiſtance to motion; and although, by giving the extreme ones a triangular end (which would be the eaſieſt executed), the reſiſtance would be leſſened nearly as the † ſines of the angles of incidence: yet other in-

* The damage ariſing from the rectangular tranſverſe ſection of boats for inclined planes is conſiderable, and can only be remedied by incurring inconveniences in the conſtruction of the boat; and the capability of its ſuſtaining itſelf on a frame without ſtraining, unleſs uncommon accuracy were attended to, in ſuiting the boats bottoms and their cradles to each other.

† At firſt in a greater ratio, afterwards in a leſs, according to the experiments of Abbé Boſſut.

If one leg of the iſoſceles triangle forming the entrance, or end, of a boat be aſſumed as radius, the reſiſtance would be as the ſquare of the ſines of the angle of incidence; but then the width of the boat would decreaſe or increaſe, as the ſine is to radius; conſequently, in boats of equal width, the reſult would be as the ſine.

conveniences

conveniences would ensue; as the boats would be attended with a great lateral wave, tending to tear town the banks, and a reduction of burthen equal to half the projection of the ends, which must, of course, be counterbalanced by an increase of length. I therefore recommend the ends of each set of boats, to be formed like an obtuse pointed gothic arch, as the dotted lines in *fig.* II. *plate* II. where, by only an increased length of one foot, an equal, or rather superior burthen to the square ended boats will be obtained; and the resistance reduced, according to the experiments of Admiral Chapman and Monsr. de Rommé, because the half width of the boat is only three fourths of the axes of the curve forming each side of its end; and, by their experiments, the resistance is equal (under any proportion of extreme width and space from thence to the stem), whether the sides for that extent form a curved water line, or go straight forward to the stem, and form two sides of a triangle.

According to the experiments tried at Greenland Dock, by the Society for the Improvement of Naval Architecture, the resistance of a vessel with semicircular ends, moving at the rate of eight feet per second, and 11¼ times as long as broad, was nearly .78 of that of the same vessel (or body composed of logs of timber) with square ends. By these experiments, and those tried at Versailles by L'Abbé Bossut, the chief advantage is derived from the form of the end moving foremost: which will hold good in all velocities with which boats can move on Canals; and, as the proposed ends are formed of half segments of circles, whose axis, in the line of the keel, is once and a third the greatest ordinate, or half width of the boat, the resistance should, according to the sines of the angles of incidence of equal threads (or minute portions) of the width of the water intercepted, be .901 of the resistance of a semicircular end, and therefore .702 of that of a square * end, according to the experiments quoted, which nearly agrees with the sines † of the angles of incidence on equal and minute portions of width.

* This advantage, in the experiment quoted, would be partly derived from an equal sharpness in the after end, which will not operate against the present case, as each end of every set of boats should be similar for the purpose of tracking either way.

† According to this theory the resistance of a semicircular end proportioned to a square one is as .7854 to one, because the sum of the natural sines of a quarter of a circle, taken on equal portions of its greatest ordinate, infinitely near, must obviously form its area.

In

In all experiments, the proportionate lengths of the rectilinear part of the bodies to their widths, and in many instances of the latter to their depths immerfed, will produce different refults: therefore, until the effects of thefe and of other attendant circumftances be known, and introduced into the formulæ, no theoretic refult can be perfectly correct; but will give more or lefs than any particular experiment, unlefs where oppofite caufes counterbalance each other; amongft which, friction on the furface expofed to the water, and the inequalities of that furface, are not the leaft confiderable.

# CHAP. IV.

*On the Metacentre or Axis of Motion of Vessels of a uniform Figure throughout their Length, shewing by several Theoretic Instances to what Height such Boats may safely carry their Cargoes. Also on the Means of combining the Navigation of small and great Canals.*

AS Canal vessels, especially the narrow ones, which are principally the subject of this Treatise, are generally of a uniform figure throughout their length, or axis of motion; except a short space at each end, which, from their great comparative length, constitutes an inconsiderable portion of the whole, I shall consider them as such; as it not only sufficiently approximates the truth, but divests the question of the intricacy that would otherwise attend it. This subject having been treated with great ability by Mr. Atwood *, in the Philosophical Transactions for 1796, I shall occasionally recur to him, for the rules necessary for investigating this matter.

In all vessels there is, at every given depth to which they may be laden, a certain altitude of the centre of gravity, at which the vessel will be on an equilibrium of indifference whether to remain at rest, or move a greater or lesser distance round its axis of motion; which axis (in the line of the vessel's length) is usually called the Metacentre: consequently, if the centre of gravity of the vessel and cargo combined, lie above the metacentre, the vessel must overturn; and, according to the distance of the centre of gravity below that point, the greater or less will be the stability of the vessel. Its resistance to overturning, if it be of a circular transverse section, will be equal to the sine of the angle of heeling, multiplied into the

* The Construction and Analysis of Geometrical Proportions determining the Position assumed by Homogeneal Bodies which float freely, and at rest on a Fluid's Surface; also determining the Stability of Ships, and of other Floating Bodies: by George Atwood, Esq. F. R. S.