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AND THE RECORDING OF  
**AMERICAN AND OTHER PATENTED INVENTIONS.**

NOVEMBER, 1831.

*Propositions and Suggestions on the means of obviating or lessening the accidents incident to Navigation by Steam. By JOHN S. WILLIAMS, Engineer.*

TO THE EDITOR OF THE JOURNAL OF THE FRANKLIN INSTITUTE.

SIR,—I have with much satisfaction read the remarks of Mr. Earle, (vol. vii. p. 154,) on the causes of some explosions in steam boilers. I fully believe the reasons he assigns, and the conclusions he arrives at, to be correct. Apprehending, however, that he has been too brief respecting preventives, I shall add a few paragraphs upon this subject; in doing which I shall not confine myself to any one particular class of accidents to which navigation by steam is liable.

Upon the western waters, steam boats have, at an average, from 4 to 5 boilers each, of 36 inches in diameter, and 18 feet long, with two flues of 13 inches in diameter, running from end to end of each boiler. These boilers are placed upon a horizontal bed occupying a breadth of from 12 to 15 feet across the fore part of the boat.

A very large proportion of the explosions of boilers, say five-sixths, are occasioned by the collapsing of the flues, and not, as is commonly reported, by the bursting of the boiler proper. The reason of this appears to be that metal of the strength to resist a rent is by no means adequate to prevent a collapse. The ability of flues to sustain the pressure of the steam, is the mere stiffness of the metal in conjunction with the perfect regularity with which the arch or circular shape of the flue is constructed and maintained. Should one diameter of a flue exceed another only by one inch, when the steam

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is up to 100 pounds upon the square inch, there would, in a flue 18 feet long, be 21,600 pounds of force applied directly to produce a collapse. There is little danger attending the collapse of a good flue, save from the rending of the metal from the head of the boiler, which is very apt to take place. Flues, however, have collapsed without leaking a drop, and consequently without further damage than the loss of the flue itself; this has happened when the boiler heads have been made of wrought iron, but perhaps never with cast heads, which ought to be rejected. Cast heads are apt to crack by frequent heatings, and when they give way, they deal destruction fore and aft.

I agree with Mr. Earle in the idea that it injures boilers and flues to be overheated, even if they should not explode at the time. I am fully persuaded that metal overheated under a high pressure is never again so fit to bear pressure either as a boiler or flue. Perhaps the reason may be that, to lower the temperature of iron a little, and suddenly, under a high pressure, operates upon the structure of the metal the same as to cool it to a greater degree under a less pressure. Not only ought the overheating of boilers and flues to be guarded against with all possible care on this account, but because the overheating is very likely to generate a quantity of highly rarified steam, to the destruction of boiler, boat, and crew, by a sudden explosion. The most common causes of the overheating of boilers and flues are, undoubtedly, carelessness, or want of skill, in the engineer, who may let the water get too low; an unnoticed failure of the force pump to perform its duty; the rolling of the boat in a heavy sea; or any thing else that causes the boat to tilt, such as the running of passengers to the side next to an approximate town or shore, combined with the discharge and reception of freight, and the reception of wood at the same side. This occasions the water to flow through the connexions from the higher boilers to the lower, and this again increases the bias, and draws more water after it. The best height of water for generating steam, is when the flues are kept just covered by it, and no more. Hence some engineers run the water very close, not allowing it to rise more than one or two inches over the flues. It is then plain that a small tilt or bias in the boat will lay the flues in one, or more, of the boilers, instantly bare, which soon becomes much heated, and generates a quantity of highly elastic steam upon the boat being restored to its level, so as to cause the water to take its proper position. In this situation, should the heated flue have the least irregular shape, so as to *favour* such a circumstance, it will collapse vertically, because the heated part of the flue is robbed, by the heat, of its stiffness, which is its only means of supporting its burthen. But should a flue thus partially heated, have been constructed perfectly cylindrical, I presume the collapse will then be horizontal, inasmuch as heating the upper part necessarily lengthens the horizontal diameter. Unless the boilers be uncommonly strong, the steam thus suddenly generated, must get vent either by valves or by an explosion; in many instances, by collapse only, but most destructively by bursting.

I now proceed to give some ideas as to the most likely means of

preventing such occurrences. In order to prevent the danger attending the tilting or sidelong position into which boats will necessarily be thrown at times, it is suggested that the boilers be unconnected, and that each be supplied by a force pump separately. But should this be thought troublesome and expensive, let the pipe from the force pump have a branch running to each boiler separately; let each of these boilers be furnished with a valve and stop cock, the valve opening towards the boiler; and let the steam pipes also, which lead out of each boiler, be furnished with a valve opening towards the cylinder. It is evident that in a boat where the boilers were thus connected, or rather, thus disconnected, no water could flow from the higher towards the lower boilers, were the boat tilted ever so much. In this case, the flues would be relieved of much of their present exposure to heat, because the water in each boiler must waste by evaporation, not flow out, before its flues would be laid bare. Thus, even were no water pumped in, twenty minutes or half an hour might be spent in this situation, without exposing the flues, under the calculation that the perpendicular waste of water is about an inch in ten minutes while running. Further; boilers thus situated would be less dangerous, not only because the flues and sides would be less exposed to heat, but because, even supposing them heated, they would not be subjected to a sudden reflux of water from the other boilers upon the boat being restored to her proper trim. It is conceded that should the force pumps play while the boat is out of trim the water would be thrown into the lower boilers, and after the trim should be restored, into the others, until all would be on a level; but the introduction of stop cocks into the pipes furnishes the means of regulating the supply of water in any position. By making a hole in one side of these pipes, and introducing three-way-cocks, means are also obtained of drawing off the water from any one, or all, of the boilers, separately, if the supply pipes are lower than the boilers.

In the steam pipe of each boiler, by which it is connected to the common steam pipe, a valve should be placed, opening upwards. Each boiler would thus give its supply of steam independently of the others, and if from any accident steam ceased to be generated in one, its valve would be closed by the pressure of steam from the other boilers, and all waste be thus prevented.

The valves above mentioned to be placed in the steam pipes would, by no means, obstruct the passage of the steam from the boilers to the cylinder, neither would they prevent the perfect equilibrium of the steam to the creation of any danger. The steam in each boiler would maintain the same pressure as the steam in the common pipe or cylinder, or be below that pressure. Let the safety valve be placed on the common pipe where the steam from all the boilers unites. In this case any one boiler which might be suddenly surcharged with steam would open and occupy the whole capacity of the safety valve for its own relief, which would thus be more effectual. Again; under this disposition of boilers, a surcharge in one would not occasion the collapse of a weak or misshapen flue in another, nor another boiler, that might be deficient, to burst. On a boat with five boilers and ten

flues, connected in the common way, the chances are against the bursting or collapsing taking place in the same boiler in which the cause of the accident occurs; but under this arrangement, both must take place in one, or the accident will not happen, by reason of the surcharged boiler being sufficient to bear the pressure. It seems to me that this would greatly lessen the number of accidents. Under the present arrangement, when one flue or boiler gives way, all the power of every boiler is exerted through the connexions, and acts upon the deficient one to render the destruction complete; but under the arrangement here proposed, the power of one boiler only would be exerted upon the boat, its contents, and crew. This is certainly an important consideration, which would hold good in all cases of collapse, and seldom fail in cases of bursting, were the boilers properly secured in their places. But further, there would another advantage attend this proposed arrangement, which, though mentioned last, may be equally worthy of consideration with the preceding. It is this—that in case of an accident, by collapse or by bursting, if the whole bed should not be deranged, not a stroke of the piston would be lost. The remainder of the boilers would not cease to drive the engine, although with diminished power. The vessel would still be under the command of the pilot, and enable him to pursue his voyage or to run into port, where medical aid and other comforts, might be obtained for the wounded. This circumstance alone would take off much of the appalling aspect of such occurrences. For part of a crew to be killed, and others crippled, and, withal, for the boat under these, the most distressing, circumstances, to be completely deprived of power, is such a picture as I can hardly bear to contemplate when I draw it; neither would it be drawn did I not believe myself to be urging measures to lessen the frequency of its occurrence as well as the horror of its features. It is true that after such an accident has occurred to one of the boilers, and, of course, all the pressure in it taken off, all the water from the force pump would be thrown into this deficient boiler. But in the course of 15 or 20 minutes, before any danger from running without a supply would occur, the engineer or some one, might turn the stop cock leading into that boiler, and force the supply into the others, when every thing would go on as before the accident, with the loss of only so much power as had been obtained from the injured boiler.

While on the subject of lessening the force of such accidents, in the destruction occasioned by them, permit me to recommend what has been repeatedly urged by others, that an almost impregnable partition be constructed to defend the lives of those passengers who shall keep their proper places. A strong bulk-head placed aft of the flues, would dissipate the force of the steam in the fire bed and through the sound flues, if the discharge was backward, as the contents of one only would have to be guarded against; and chimneys well secured, and of nearly equal strength with the boilers, would be likely to turn all the contents of one boiler upward. In this way the life of many a fireman, as well as those of passengers, would be saved.

As explosions by bursting are the more destructive, so those by collapses are the more frequent; thus by them, many lives and much property are lost. Every precaution that ingenuity can devise, or discretion suggest, ought to be adopted to prevent their occurrence, and lessen their destructive effects when they do occur. Let, then, the strength of metal be increased, or the diameters of both boilers and flues be diminished, and their numbers increased, to accomplish the same ends. Although our means of precaution may be expensive or troublesome, (which is not admitted to be the fact,) yet the increased confidence and business of that mode of conveyance, would amply repay the prudent, as well for a small expense, as for the additional care in keeping their boilers clear of earthy and saline matter, which tends greatly to their decay, if not to their sudden and total destruction.

After having suggested several improvements in supplying boilers with the common pump, allow me to take a brief notice of a patent obtained by me, for what I believe to be an improved method of supplying the boilers of steam engines with water. I mention it with hesitancy, although I have much confidence in its utility, but am not now so situated as to put it into operation myself; should any one, however, conceive it worth an experiment, and apply to me, post paid, for a right to use it, I hope to convince him that a sordid love of gain forms no part of my composition. This invention was published by you, with a cut, in March last, vol. vii. p. 183. A common boiler would require the water chamber, B, [see the cut,] to be from 6 to 9 inches cubic; and the reservoir might be nothing more than a pipe or apartment kept supplied by a fount from the condenser, the hot well, or the cold water pump. The whole structure might be attached to the main head, and with it removed, cleaned, inspected, or repaired, with the greatest ease and convenience. The cut shows the principle in the easiest way it could be presented to the eye, but not the most convenient mode of applying it to the machinery. Instead of the cocks, E and F, a sliding escapement, a four-way-cock, or a double conic valve, will be easy to construct, and readily connected with the motion of the engine. A wooden float in the chamber B, would prevent condensation by separating the steam from the water. The apparatus can be attached to any part of, and all sorts of boilers, or connected with them by pipes, provided the necessary levels are preserved.

I propose that one apparatus should be attached to each boiler in boats, with valves in the steam pipes, as above recommended. To the advantages gained by the above arrangement, with the common force pump, I presume the following will be added; my apparatus will require no stuffing, and have fewer wearing parts; it would introduce no greasy and linty substances into the boilers, which, combining with earthy matter, sometimes form blackberries, (so called,) which burn to the bottom; it requires less power to keep it going, and by a small discharge of steam at every operation, would notify its proper action; it will keep the water in the boilers always at the same height, by discharging more than the waste when the water

is too low, and less when it is too high in the boiler, if accident or design should make it so. Thus by its own operations, would it find the proper height for the water, and steadily maintain it at that height as long as the operation goes on, and the supply kept up. And, lastly, should the boat lie ever so sidelong, it would keep in every boiler its proper supply of water.

But, after all, accidents will occur, under the management of unskilful and careless engineers; boat owners are frequently imposed upon by vagrants under that name. The remarks of your correspondent, R. D. H. published in vol. vii. p. 289, are, in the main, very judicious, and I hope he will succeed in his experiments. Safety valves are certainly a security, if properly constructed, and left to operate freely; but they are often tied down, and are thus rendered useless. I lately passed a boat in which I know that the engineer had been in the constant practice of tying his safety valve down under the power of a double lever. I passed by it in another boat, and, as might be expected, death and destruction had visited the spot. I could enlarge, but charity throws a veil over the past, and seeks a future remedy. Let those who are competent devise it, and those who have power and means carry it into effect. Let there be a Board of Inquiry to examine the moral standing and skill of engineers and pilots; let boilers be tested, let large safety valves be placed out of the reach of all on board, let the causes of accidents be inquired into, or let any method, in any way promising, be adopted and pursued that might tend to lessen the evil, and increase the chances of escape.

Another class of accidents to which steam boats are liable is that of fire. Is it not almost incredible that a vessel whose very propelling power arises from fire, and in which a profuse application is made of oil, which is built of the most light and combustible materials, exposed to numberless sparks, and the constant heat of a furnace, should be seldom or never guarded against consumption by fire? Would not a force pump, worked by the engine, supplied with hose, be a necessary appendage to them?

Boats running into and sinking each other, and boats burned to the water's edge in a few minutes, boilers bursting, and flues collapsing, together with the attendant death and destruction, make up a considerable amount of human ills, which call loudly upon the powerful and the humane for their exertions to arrest. Power by steam, managed as it might be, would not only be the easiest and cheapest mode of transit for goods and passengers, but the safest also; but for the want of skill or attention, our use of it has increased greatly beyond our provisions for rendering it so.

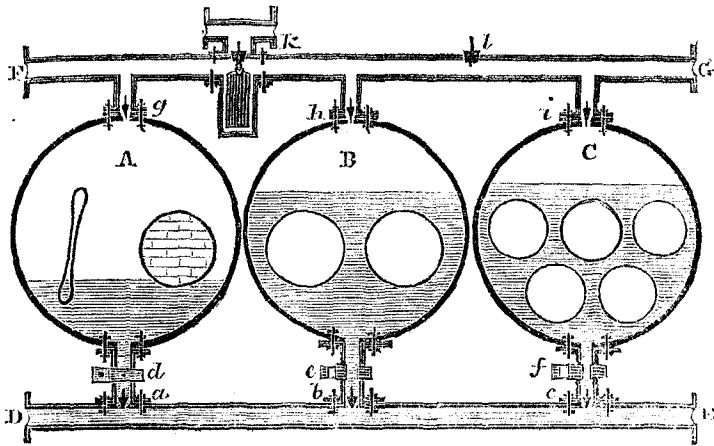
Being deeply impressed with the importance of my subject, it has been extended to a greater length than I had anticipated; if I have been tedious, let the motive plead my excuse with your readers.

Yours respectfully,

JNO. S. WILLIAMS.

*Washington, Mason county, Ky. Sept. 12, 1831.*

*Notes and references explanatory of the accompanying drawing, and Illustrative of the mode of connecting boilers recommended in the foregoing essay.*



A B C, sections of three boilers placed at or near a level.

D E, supply pipes. *a b c*, valves opening from the supply pipe towards the boilers. *d e f*, stop cocks between said valves and the boilers, which by being made three-way-cocks, may serve to drain the boilers.

F G, steam pipes leading from the boilers to the cylinder. *g h i*, valves opening from the boilers towards the cylinder. *k l*, safety valves, one of which might be encased with its burthen, even inside of the boiler or pipe, as at *k*.

Boiler A has one flue collapsed and the other walled up to prevent a draft. The deficient boiler may have as much water kept in it as it will hold, to prevent burning. Meanwhile boilers B and C have not ceased for a moment to supply steam, and, consequently, power, to the cylinder.

Boiler C is placed in a manner that is believed would not be subject to collapses, and at the same time generate much more steam than the common method in proportion to the weight of the boiler and water.





TABLE I.—PART II.  
CHUTE No. 4.—Elbow buckets. Close breast. Bottom of gate 10.46 feet above bottom of wheel.

No. of Experiment.	Head of water above, feet.		Width of Aperture, In.	Weight raised, Pds.		Friction, Pounds.	Sum of friction and weight raised, Pounds.		Height raised, Feet.	Time, Secs.	Velocity per second, Feet.		Work expended, Pds. Feet.		Head and fall, Feet.		Power, Effect.	Ratio, power being 1.	Maximum effect.	Velocity at maximum.	Observations.
	Feet.	Btm. of gate, bkt.		Feet.	Btm. of gate, bkt.																
17	10.29	12.22	13.47	0.75	669	51.81	720.81	41.5	32	12.20	3475	20.75	721062	299136	414						
18					772	83.62	825.62		33	11.84	3800		788300	342632	434						
19					875	55.43	930.43		38	10.28	4175		866312	386128	445						
20					978	57.24	1035.24		41	9.33	4600		954500	429624	450						
21					1081	59.05	1140.05		46	8.50	5125		1063437	473120	445						
22					1184	60.86	1244.86		51	7.66	5700		1182750	516617	435						
23					1287	65.23	1352.23		57	6.86	6300		1307250	561175	428						
24					1390	69.60	1459.60		64	6.10	7050		1462875	605734	414						
25	10.29	12.22	13.47	1.00	875	55.43	930.43	41.5	29	13.48	4425	20.75	918187	386128	420						
26					1081	59.05	1140.05		35	11.16	5050		1047875	473120	451						
27					1184	60.86	1244.86		38	10.28	5585		1158887	516617	445						
28					1287	65.23	1352.23		40	9.77	6100		1265850	561175	443						
29					1390	69.60	1459.60		45	8.71	6675		1385062	605734	437						
1									9	10	11	12	13	14	15	16	17	18			

CHUTE No. 4.—*Elbow buckets. Close breast. Bottom of gate 10.46 feet above bottom of wheel.*

TABLE I.—PART III.

No. of Expt.	Head of water above.		Feet.	Feet.	Feet.	In.	Width of Aperture.	Weight raised.	Friction.		Sum of friction and weight raised.	Height raised.	Time.	Velocity per second.		Work expended.		Head and fall.	Power.	Effect.	Ratio, power being 1.	Maximum effect.	Velocity at maximum.	Observations.
	Run. of gate.	Top of of bkt.	Run. of of bkt.						Pds.	Pounds.				Feet.	Feet.	Feet.	Pds.							
30	7.29	9.22	10.47	0.75	566	50.00	616.00	41.5	33	11.84	3300	17.75	58750	255640	.436									
31					669	51.81	720.81		38	10.28	3625		643437	299136	.465									
32					772	53.62	825.62		41	9.54	4075		723312	342632	.473									
33					875	55.43	930.43		47	8.32	4350		807625	386128	.478									
34					978	57.24	1035.24		53	7.38	5125		909687	429624	.472									
35					1081	59.05	1140.05		58	6.74	5700		1011750	473120	.467									
36					1184	60.86	1244.86		65	6.00	6375		1131563	516617	.456									
37					1287	65.23	1352.23		73	5.35	7125		1264687	561175	.443									
38	7.29	9.22	10.47	1.00	978	57.24	1035.24	41.5	39	10.02	4925	17.75	874187	429624	.491									
39					1081	59.05	1140.05		43	9.09	5400		958500	473120	.493									
40					1184	60.86	1244.86		46	8.50	6000		1065000	516617	.485									
41					1287	65.23	1352.23		52	7.52	6575		1167062	561175	.480									
42					1390	69.60	1459.60		58	6.74	7325		1283437	605734	.473									
43					1493	73.97	1566.97		63	6.20	7850		1393375	650293	.466									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18							

CHUTE No. 4.—Elbow buckets. Close breast. Bottom of gate 10.46 feet above bottom of wheel.

TABLE I.—PART IV.

No. of Expt.	Head of water above.			Width of Aperture.	Weight raised.	Friction.	Sum of friction and weight raised.		Height raised.	Time.	Velocity per second.	Work expended.		Head and fall.	Power.	Effect.	Ratio, power being 1.	Maximum effect.	Velocity at maximum.	Observations.
	But. of gate.	Top of bkt.	Bot. of bkt.		Pds.	Pounds.	Pounds.	Feet.		Secs.	Feet.	Feet.	Pds.	Feet.						
44	4.29	6.22	7.47	0.75	463	48.19	511.19	41.5	38	10.28	3010	14.75	44397.5	2151.44	477					Experiments were made on a head of 11.75 feet, but the back of the chute was too high to permit a flow sufficient to fill the aperture; in consequence of this, the ratios did not increase in a due proportion to the diminution of the head. It has not been deemed necessary to record those experiments in the tables.
45					566	50.00	616.00		45	8.71	3475		512562	253640	498					
46					669	51.81	720.81		50	7.82	3975		586312	299136	510					
47					772	53.62	825.62		57	6.85	4525		667437	342632	513					
48					875	55.43	930.43		66	5.92	5150		759625	386128	508					
49					978	57.24	1035.24		75	5.21	5875		866562	429624	495					
50					1081	59.05	1140.05		85	4.60	6650		980875	473120	482					
51	4.29	6.22	7.47	1.00	772	53.62	825.62	41.5	43	9.09	4350	14.75	641625	342632	534					
52					875	55.43	930.43		48	8.14	4860		716830	386128	538					
53					978	57.24	1035.24		55	7.10	5450		803870	429624	534					
54					1081	59.05	1140.05		59	6.62	6075		896062	473120	528					
55	4.29	6.22	7.47	1.25	875	55.43	930.43	41.5	40	9.77	4850	14.75	718370	386128	537					
56					978	57.24	1035.24		44	8.88	5350		789120	429624	544					
57					1081	59.05	1140.05		49	7.98	5925		873937	473120	541					
58					1184	60.86	1244.86		54	7.24	6575		969812	516617	532					
59					1287	62.23	1352.23		61	6.40	7225		1065687	561175	526					
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18			

TABLE K.—PART I.  
CHUTE No. 4.—Centre buckets. Bottom of gate 10.46 feet above bottom of wheel.

No. of Expt.	Head of water above.				Width of Aperture.	Weight raised.	Friction.		Sum of friction and weight raised.	Height raised.	Time.	Velocity per second.		Water expended.	Head and fall.	Power.	Effect.	Ratio, power being 1.	Maximum effect.	Velocity at maximum.	Observations.
	Butt. of gate.	Top of bkt.	Butt. of bkt.	Feet.			Pounds.	Pounds.				Feet.	Secs.								
1	12.54	14.47		15.72	0.50	360	46.38	406.38	41.5	38	10.28	2210	23.00			508300	168647	.331			
2						463	48.19	511.19		47	8.32	2650				609500	212144	.348			
3						566	50.00	616.00		55	7.10	3135				721050	255640	.354	.354	7.10	
4						669	51.81	720.81		66	5.92	3710				853300	299136	.350			
5	12.54	14.47		15.72	0.75	669	51.81	720.81	41.5	33	11.84	3420	23.00			786600	299136	.380			
6						772	53.62	825.62		38	10.28	3800				874000	342632	.393			
7						875	55.43	930.43		40	9.77	4155				955650	386128	.404			
8						978	57.24	1035.24		43	9.09	4560				1048800	429624	.409	.409	9.09	
9						1081	59.05	1140.05		46	8.50	5050				1161500	473120	.407			
10						1184	60.86	1244.86		48	8.14	5525				1270750	516617	.406			
11						1287	65.23	1352.23		53	7.38	6125				1408750	561175	.398			
12	12.54	14.47		15.72	1.00	772	53.62	825.62	41.5	29	13.48	3910	23.00			893730	342632	.383			
13						875	55.43	930.43		32	12.20	4160				956800	386128	.403			
14						978	57.24	1035.24		36	10.86	4560				1048800	429624	.409			
15						1081	59.05	1140.05		39	10.02	4990				1147700	473120	.412			
16						1184	60.86	1244.86		40	9.77	5375				1236250	516617	.418	.418	9.77	
17						1287	65.23	1352.23		43	9.09	5850				1345500	561175	.417			
18						1390	69.60	1459.60		46	8.50	6375				1466250	603734	.413			
19						1493	73.97	1566.97		53	7.38	7105				1634150	650293	.398			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18				

TABLE K.—PART II.  
CHUTE No. 4.—Centre buckets. Bottom of gate 10.46 feet above bottom of wheel.

No. of Exports.	Head of Water above.		Width of Aperture.	Weight.	Friction.	Sum of friction and weight raised.	Height raised.	Time.	Velocity per second.	Work expended.	Head and fall.	Power.	Effect.	Ratio, power being 1.	Maximum effect.	Velocity at maximum.	Observations.
	Feet.	Btm. of gate.		Pds.	Pounds.	Pounds.	Feet.	Secs.	Feet.	Pds.	Feet.						
20	10.29	12.22	13.47	0.50	360	46.38	406.38	41.5	39	10.02	2370	20.75	491775	168647	343		
21					463	48.19	511.19	47	8.32	2830			587225	212144	361		
22					566	50.00	616.00	50	7.82	3250			674375	255640	379	7.82	
23					669	51.81	720.81	67	5.84	3950			819625	299136	364		
24	10.29	12.22	13.47	0.75	669	51.81	720.81	41.5	35	11.16	3635	20.75	754262	299136	396		
25					772	53.62	825.62	39	10.02	4000			830000	342632	413		
26					875	55.43	930.43	41	9.54	4430			919225	386128	420		
27					978	57.24	1035.24	47	8.32	4910			1018325	429624	421	8.32	
28					1081	59.05	1140.05	54	7.24	5470			1135025	473120	416		
29					1184	60.86	1244.86	59	6.62	6065			1258487	516617	410		
30	10.29	12.22	13.47	1.00	978	57.24	1035.24	41.5	38	10.28	4780	20.75	991850	429624	433		
31					1081	59.05	1140.05	40	9.77	5200			1079000	473120	438		
32					1184	60.86	1244.86	44	8.88	5645			1171337	516617	441	8.88	
33					1287	65.23	1352.23	48	8.14	6275			1302062	561175	431		
34					1390	69.60	1459.60	54	7.24	6900			1431750	603734	423		
35	10.29	12.22	13.47	1.25	1081	59.05	1140.05	41.5	32	12.20	5150	20.75	1068625	473120	442		
36					1184	60.86	1244.86	35	11.16	5580			1157850	516617	446		
37					1287	65.23	1352.23	37	10.56	5880			1220100	561175	460	10.56	
38					1390	69.60	1459.60	41	9.54	6450			1338375	603734	452		
39					1493	73.97	1566.97	44	8.88	7000			1452500	650293	447		
1	2	4	3	5	6	7	8	9	10	11	12	13	14	15	16	17	18

TABLE K.—PART III.  
CHUTE No. 4.—Centre buckets. Bottom of gate 10.46 feet above bottom of wheel.

No. of Experiment.	Head of water above.				Width of Aperture.	Weight raised.	Friction.		Sum of traction and weight raised.	Height raised.	Time.	Velocity per second.		Work expended.		Head and fall.		Power.	Effect.	Ratio, power being 1.	Maximum effect.	Velocity at maximum.	Observations.
	Bin. gate.	Top of bkt.	Bin. bkt.	Feet.			Pds.	Pounds.				Feet.	Feet.	Pds.	Feet.								
40	7.29	9.22	10.47	0.50	257	44.57	301.57	41.5	37	10.56	2050	17.75	363875	125152	.344								
41					360	46.38	406.38		45	8.70	2520		447300	168647	.377								
42					463	48.19	511.19		53	7.38	3010		534275	212144	.397								
43					566	50.00	616.00		64	6.10	3575		634562	255640	.403								
44					669	51.81	720.81		73	5.35	4160		738400	299136	.405						405.535		
45					772	53.62	825.62		86	4.54	4875		865312	342632	.396								
46					875	55.43	930.43		105	3.72	5700		1011750	386128	.381								
47	7.29	9.22	10.47	0.75	669	51.81	720.81	41.5	42	9.31	3833	17.75	680712	299136	.439								
48					772	53.62	825.62		46	8.50	4240		752600	342632	.455						455.850		
49					875	55.43	930.43		52	7.52	4790		850225	386128	.454								
50					978	57.24	1035.24		58	6.74	5350		949635	429624	.452								
51	7.29	9.22	10.47	1.00	875	55.43	930.43	41.5	42	9.31	4673	17.75	829812	386128	.465								
52					978	57.24	1035.24		46	8.50	5110		907350	429624	.473						473.850		
53					1081	59.05	1140.05		50	7.82	5650		1002875	473120	.471								
54					1184	60.86	1244.86		54	7.24	6225		1104937	516617	.467								
55					1287	65.23	1352.23		62	6.30	6935		1230962	560175	.455								
56	7.29	9.22	10.47	1.25	978	57.24	1035.24	41.5	37	10.56	5120	17.75	908800	429624	.472								
57					1081	59.05	1140.05		39	10.92	5500		976250	473120	.484								
58					1184	60.86	1244.86		44	8.38	6000		1065000	516617	.485						485.888		
59					1287	65.23	1352.23		47	8.32	6530		1159075	560175	.483								

CHUTE No. 4.—Centre buckets. Bottom of gate 10.46 feet above bottom of wheel.

TABLE K.—PART IV.

No. of experiment.	Head of water above.			Width of aperture.	Weight raised.	Friction.	Sum of friction and weight raised.	Height raised.	Time.	Velocity per second.	Water expended.		Power.	Effect.	Ratio, power being 1.	Maximum effect.	Velocity at maximum.	Observations.
	Bin. of gate.	Top of bkt.	Bin. of bkt.								Feet.	Pds.						
	Feet.	Feet.	Feet.	In.	Pds.	Pounds.	Pounds.	Feet.	Secs.	Feet.	Feet.	Pds.	Feet.					
60	7.29	9.22	10.47	1.30	1081	99.05	1140.05	41.5	34	11.50	5550	17.75	983125	473120	.480			
61					1184	60.86	1244.86		38	10.28	5950		1056125	516617	.489			
62					1287	63.23	1352.23		40	9.77	6400		1136000	561175	.494			
63					1390	69.60	1459.60		43	9.09	6850		1215875	605734	.498	4.98	9.09	
64					1493	73.97	1566.97		46	8.50	7500		1331250	650293	.488			
65					1596	78.34	1674.34		50	7.82	8110		1439525	694831	.482			
66	4.29	6.22	7.47	0.75	463	48.19	511.19	41.5	47	8.32	3175	14.75	468312	212144	.453			
67					566	50.00	616.00		57	6.86	3725		549437	235640	.465			
68					669	51.81	720.81		66	5.92	4270		629825	299136	.474	4.74	5.92	
69					772	53.62	825.62		76	5.14	4975		733812	342632	.466			
70	4.39	6.22	7.47	1.00	566	50.00	616.00	41.5	40	9.77	3700	14.75	545750	235640	.468			
71					669	51.81	720.81		46	8.50	4150		612125	299136	.488			
72					772	53.62	825.62		52	7.52	4635		683662	342632	.500			
73					875	55.43	930.43		58	6.74	5166		761100	386128	.507	.507	6.74	
74					978	57.24	1035.24		64	6.10	5750		848125	429624	.506			
75					1081	59.05	1140.05		71	5.50	6410		943475	473130	.500			
76	4.29	9.22	7.47	1.25	875	55.43	940.43	41.5	46	8.50	5000	14.75	737500	386128	.523			
77					978	57.24	1035.24		50	7.82	5500		811250	429624	.529	.529	7.82	
78					1081	59.05	1140.05		56	6.98	6100		899750	473130	.525			
79					1184	60.86	1244.86		61	6.40	6700		988250	516617	.522			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	

CHUTE No. 4.—Centre buckets. Bottom of gate 10.46 feet above bottom of wheel.

No. of exper't.	Head of water above.			Width of Aperture	Weight raised.	Friction.	Sum of friction and weight raised.	Height raised.	Time.	Velocity		Work expended.	Head and fall.		Power.	Effect.	Ratio, power being 1.	Maximum effect.	Velocity at maximum.	Observations.
	Bin. of gate.	Top of bkt.	Bin. of bkt.							Feet.	Secs.		Feet.	Fds.						
80	4.29	6.23	7.47	1.30	978.57.24	135.24	41.5	43	9.09	5470	14.75	806825	429624	.532						
81					1081.59.05	1140.05		46	8.50	5875		866562	473120	.546				.546	8.50	
82					1184.60.86	1344.86		51	7.56	6525		962437	516617	.536						
83					1287.65.23	1352.23		56	6.98	7135		1052412	561175	.533						
84	4.29	6.22	7.47	1.75	1081.59.05	1140.05	41.5	35	11.16	6325	14.75	932937	473120	.507						
85					1184.60.86	1244.86		37	10.36	6765		997837	516617	.517						
86					1287.65.23	1352.23		39	10.02	7135		1050931	561175	.534						
87					1390.69.60	1459.60		43	9.09	7625		1124687	603734	.538						
88					1493.73.97	1566.97		44	8.88	8050		1187375	650293	.547				.547	8.88	
89					1596.78.54	1674.34		56	6.98	8875		1309062	694851	.530						
90	1.54	3.47	4.72	1.00	257.44.57	301.57	41.5	41	9.54	2350	12.00	282000	125152	.443						
91					463.48.19	511.19		60	6.50	3400		408000	212144	.520						
92					566.50.00	616.00		70	5.58	4010		481200	235640	.531						
93					669.51.81	720.81		82	4.77	4650		558000	399136	.556				.556	4.77	
94					772.53.62	825.62		95	4.11	5400		648000	342632	.528						
95					875.55.43	930.43		110	3.55	6225		747000	386128	.517						
96	1.54	3.47	4.72	1.25	566.50.00	616.00	41.5	57	6.86	3910	12.00	469200	255640	.544						
97					669.51.81	720.81		67	5.84	4475		537000	299136	.556						
98					772.53.62	825.62		74	5.28	5100		612000	342632	.559				.559	5.28	
99					875.55.43	930.43		86	4.54	5935		712200	386128	.542						
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18			



TABLE K.—Part VI.  
CHUTE No. 4.—Centre buckets. Bottom of gate 10.46 feet above bottom of wheel.

No. of Exptl.	Head of water above.			Width of Aperture.	Weight raised.	Friction.	Sum of friction and weight raised.	Height raised.	Time.	Velocity per second.	Work expended.	Head and fall.	Power.	Effect.	Ratio, power being 1.	Maximum effect.	Velocity at maximum.	Observations.
	Run. of gate.	Top of of bkt.	But. of of bkt.		Fds.	Pds.	Pounds.	Feet.	Secs.	Feet.	Pds.	Feet.						
100	1.54	3.47	4.72	1.50	566	50.00	616.00	41.5	49	7.98	3882	12.00	466200	255640	.548			
101					669	51.81	720.81		59	6.63	4475		537000	299136	.557			
102					772	53.62	825.62		66	5.92	5050		606000	342632	.565			
103					875	55.43	930.43		73	5.35	5630		681600	386128	.566		5.55	
104					978	57.24	1035.24		82	4.77	6465		775800	429624	.582			
105					1081	59.05	1140.05		93	4.20	7330		878400	473120	.588			
106	1.54	3.47	4.72	1.75	669	51.81	720.81	41.5	49	7.98	3882	12.00	534000	299136	.560			
107					772	53.62	825.62		55	7.10	4975		597000	342632	.574			
108					875	55.43	930.43		62	6.30	5575		669000	386128	.577			
109					978	57.24	1035.24		68	5.75	6150		738000	429624	.582		5.75	
110					1081	59.05	1140.05		79	4.95	7025		845000	473120	.561			
111	1.54	3.47	4.72	2.00	978	57.24	1035.24	41.5	58	6.73	6075	12.00	729000	429624	.589			
112					1081	59.05	1140.05		62	6.30	5675		801000	473120	.590		6.30	
113					1184	60.86	1244.86		72	5.43	7375		885000	516617	.583			
114	1.29	3.22	4.47	1.00	463	48.19	511.19	41.5	70	5.58	5455	11.75	416537	213144	.509			
115					566	50.00	616.00		82	4.77	4150		487625	255640	.524		4.77	
116					669	51.81	720.81		96	4.07	4890		574575	299136	.521			
117	1.29	3.22	4.47	1.50	566	50.00	616.00	41.5	72	5.43	4075	11.75	478812	255640	.533			
118					669	51.81	720.81		78	5.01	4700		552250	299136	.542		5.01	
119					772	53.62	825.62		94	4.16	3500		646250	342632	.530			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	