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EXPERIMENTAL RESEARCHES

ON

THE FORMS OF CANAL AND RIVER BOATS

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EXPERIMENTAL RESEARCHES ON THE FORMS OF CANAL AND RIVER BOATS.

I. Object of the Researches.

The object of the researches made during the three years 1890, 1891, 1892, was to improve the construction of boats plying alternately upon rivers and canals.

This subject has a special interest in France, where the traject in the most frequented waterways is equally divided between canals and rivers; and the boats capable of alternately navigating each form the immense majority of the boating fleet.

As the boats have to pass through locks 38.50 metres long, 5.20 metres wide, with a draught of 2 metres, this requirement unfortunately restricts their dimensions within very narrow limits, and consequently their tonnage. Again, the tendency of constructors has been to utilize as much as possible the capacity of the locks by reducing the sacrifice of space for the sake of form to a minimum. They have gone as far as possible in this direction.

The Coefficient of Displacement of a boat is the quotient, always less than the unity, of its real displacement, by the volume of a rectangular parallelopipedon circumscribed around the immersed portion; this measures the sacrifice of space made for the sake of the form of the boat in its construction. Now, for the type most used in France, the "*péniche flamande*,"* this coefficient rises to 0.99; the real displacement only differing by one one-hundredth from the volume of the parallelopipedon circumscribed around the immersed portion of the hull.

On the contrary, the result of this total absence of form, at least upon rivers, is to increase the tractive effort, and

* Dumb barge.

consequently the cost of haulage, thus materially augmenting the cost of transportation. This expense can only be lessened by improving the form, thus diminishing the coefficient of displacement, and consequently the displacement itself, and therefore the tonnage of the boat.

In what measure can we conciliate these two contradictory interests?

It is very easy to evaluate with sufficient precision the loss resulting from a diminution of the coefficient of displacement. The dimensions of the immersed part of the hull of the boats in question are subject to very slight variations: length, 38.50 metres; width, 5.00 metres; draught, 1.80 metres. The product of these in round numbers equals 350 cubic metres. The maximum displacement of these boats being 350 cubic metres, their total weight (dead weight and useful weight) does not exceed 350 tons; and each hundredth of diminution in the coefficient of displacement corresponds to a reduction of 3.50 tons at the most, in the total weight. As elsewhere, in the limits where the form may vary, we must consider the dead weight a constant. We may admit that the diminution bears entirely on the useful weight, and state the following rule. *In the construction of boats plying alternately on canals and rivers in France, each hundredth of reduction in the coefficient of displacement corresponds to a diminution of* 3.5 *tons, at the most, of freight.*

What, on the other hand, is the reduction which an improvement of form affords in the effort of traction, and consequently on the *cost* of traction, especially on the rivers? This is precisely, as we have said above, the object of our researches during the last three years.

II. Method employed in the Researches.

All our experiments have been made with the boats themselves, by means of direct towage, on a part of the Seine immediately above the upper dam at *Port à l'Anglais*, near Paris, where the width and the depth are sufficiently great to assimilate it to an indefinite stream of water, and where the velocity of the current is nearly zero in ordinary times.

The experiments made on each boat consisted in towing it successively at different speeds with a special apparatus, making continuous registration, 1st (*le dynamomètre hydraulique enregistreur*) of *the efforts* of *traction*, 2nd (*le moulinet avec enregistreur de vitesse*) of the *relative velocity* of the boat and the water in which it is towed. For the description and use of this apparatus we may refer the reader to Vol. I. of *Recherches Expérimentales sur le Matériel de la Batellerie.**

When this apparatus indicates simultaneously a constant effort and a constant relative velocity, we consider that we have accurately the effort corresponding to the velocity; and we note both. If we take the velocity for the abscissa and the effort for the ordinate, we shall have, on a chart, a point for each observation. The curve determined by the relative positions of points in the same experiment constitutes what we call the *curve of total resistance* of the boat experimented upon.

It is by comparing the curves of total resistance obtained under different circumstances that we are able tc show the characteristic properties of different crafts.

In place of the curves themselves, we can compare the resistance at certain typical velocities laid off on the said curves. This is what we shall do in the course of the present report, where we shall find for the experiments mentioned tables showing the resistance at velocities of 0.50 metre, 1.00 metre, 1.50 metres, 2.00 metres, and 2.50 metres per second.

We rarely exceed this last velocity in our experiments. Sometimes it is for the want of towage power, sometimes the guidance of the boat becomes impossible or its security is menaced. Besides, the velocity of 2.50 metres per second, or 9 kilometres per hour, may, in most cases, be considered, practically, a maximum.

*Two volumes have already appeared: they are in vellum, price 3f. They may be obtained from the following publishers in Paris: —

Mme. Vve. Dunod, Quai des Grandes-Augustins, 49.

M. M. Chaix et Cie, Rue Bergère, 20.

M. Baudry, Rue des Saints-Pères, 15.

Some experiments made in 1890 have already established the following fact: "At moderate speeds practically in use on our rivers, for boats of which the coefficient of displacement nearly approaches unity, varying between very narrow limits, the effort of traction per cubic metre of displacement,— *i.e.*, per ton dead weight and useful weight combined,—yet varies in very wide proportions, which may exceed unity and sometimes may go up to two."

The usefulness of the researches is thus manifestly confirmed: we have methodically pursued them during the two years 1891 and 1892. We give the following abridgment of the most interesting results obtained.

III. Influence of the Surface.

We have, first of all, sought how, in the same boat, the resistance to traction varies with the draught; and for this purpose the experiments have been made with the "Alma," a boat of the type called *flûte* (Plate I.), at the successive draughts of 1.00, 1.30, and 1.60 metres.

The following table shows the principal dimensions at the different draughts:—

Dimensions of the Immersed Part of the Flute "Alma."	Draught.		
	1.00 m.	1.30 m.	1.60 m.
L. Length, ...	37.54 m.	37.74 m.	37.99 m.
l. Breadth of beam, ...	5.02 m.	5.02 m.	5.02 m.
t. Draught, ...	1.00 m.	1.30 m.	1.60 m.
d. Coefficient of displacement, . . .	0.957	0.954	0.950
D. Displacement, ...	180 cu. m.	235 cu. m.	290 cu. m.

The second table, on the other hand, shows how the immersed midship section, the total wetted surface, and the resistance at the velocity types of 0.50, 1.00, 1.50, 2.00, and 2.50 metres vary with the successive draughts, for both absolute and relative values.

Data and Results relative to the Flute "Alma."	Draught.		
	1.00 m.	1.30 m.	1.60 m.
Immersed midship section, absolute: $w = l\,t$	5.02 m.	6.53 m.	8.03 m.
Immersed midship section, relative	1.00	1.30	1.60
Wetted perimeter amidships: $x = l + 2\,t$	7.02 m.	7.62 m.	8.22 m.
Immersed length: L	37.54 m.	37.74 m.	37.99 m.
Total wetted surface, absolute measured value	259 sq. m.	283 sq. m.	307 sq. m.
Total wetted surface, absolute calculated value: $d = Lx$	264 sq. m.	288 sq. m.	312 sq. m.
Total wetted surface, relative value	1.00	1.09	1.18
Total resistance at the velocity of 0.50 m., absolute	39 kg.	44 kg.	54 kg.
Total resistance at the velocity of 0.50 m., relative	1.00	1.13	1.38
Total resistance at the velocity of 1.00 m., absolute	129 kg.	143 kg.	162 kg.
Total resistance at the velocity of 1.00 m., relative	1.00	1.11	1.26
Total resistance at the velocity of 1.50 m., absolute	280 kg.	315 kg.	355 kg.
Total resistance at the velocity of 1.50 m., relative	1.00	1.13	1.27
Total resistance at the velocity of 2.00 m., absolute	502 kg.	579 kg.	664 kg.
Total resistance at the velocity of 2.00 m., relative	1.00	1.15	1.32
Total resistance at the velocity of 2.50 m., absolute	805 kg.	953 kg.	1,119 kg.
Total resistance at the velocity of 2.50 m., relative	1.00	1.18	1.39

This table shows that for the same boat, the "Alma," of which the draught varies:—

1. *The immersed midship section* increases as the draught;
2. *The total wetted surface* increases less rapidly than the draught;
3. *The total resistance* for the same velocity increases less rapidly than *the immersed midship section* and more rapidly than *the total wetted surface.*

This fact is explained by considering the *total resistance* as composed of at least two elements, the first dependent on the immersed midship section, and the other on the total wetted surface,—elements which we name respectively; *resistance of form* and *resistance of surface.*

This conception is also in accordance with the theory which considers the total resistance as composed of two terms: the first expressing the resistance proper, called *resistance of form*, and the second, the resistance due to friction, *resistance of surface.*

What is the ratio of the surface resistance to the *total resistance?* This is the vital question; for, although the boats which form the principal object of our investigations have very variable forms, the total wetted surface is perceptibly constant for the same draught. We know, in a word, that this surface is given with sufficient exactness by the formula

$$S = L\,(l \quad 2t)$$

in which the values of L and of l determined by the maximum dimensions of the canal locks are constant.

After various trials we have been led to think that the best way of appreciating the importance of the resistance of surface is to modify in different ways the nature of the surface of the same boat, and we have again used the *flûte* "Alma" for these experiments.

At first, for the sake of economy, we contented ourselves with modifying the nature of the portion of the lateral surface which emerges when the boat is empty.

This portion of the surface lies between the water line when empty and the water line when laden to a depth of 1.60 metres, at which the experiments were made, a belt of 1.26 metres in height, and 25 square metres of surface. The total wetted surface at the depth of 1.60 metres being 307 square metres, we see that the modified portion of the surface represented by 0.31 would be about ⅛ of the total surface.

The "Alma" having been first drawn on land and carefully scraped so as to bring the wood into its natural state, the zone in question was successively tarred, then covered with a coarse wrapping cloth, with a view of augmenting the friction, then with enamelled cloth so as to diminish it as much as possible. The annexed table shows the value for each experiment of this resistance at the typical velocities :—

Conditions of the "Alma" during the Experiments. *Uniform Draught of 1.60 m.*	Total Resistance at the Successive Velocities.				
	0.50 m.	1.00 m.	1.50 m.	2.00 m.	2.50 m.
Wood scraped to the natural state, ...	54 kg.	162 kg.	355 kg.	664 kg.	1,119 kg.
Zone of 1.26 m. in height tarred, ...	55 kg.	164 kg.	360 kg.	675 kg.	1,138 kg.
Zone of 1.26 m. in height covered with coarse wrapping cloth, ...	57 kg.	169 kg.	368 kg.	686 kg.	1,155 kg.
Zone of 1.26 m. in height covered with waxed cloth, ...	46 kg.	142 kg.	308 kg.	558 kg.	906 kg.

The table shows that the partial tarring has had, so to speak, no effect, since the observed differences in the total resistance at the different velocities are comprised between 1 per cent. and 2 per cent. Again, they are positive, contrary to what we should expect; but it should be observed that the "Alma" is an old boat; having great inequalities in its sides, and that, only one coat of tar being applied, it was not completely dry on the day of the experiment.

The partial covering with wrapping cloth did not very sensibly increase the total resistance. According to the different velocities, the increase varied from $3\frac{2}{10}$ per cent. to $5\frac{6}{10}$ per cent. But, as we have already said, the "Alma" is an old boat: it is certain that, in scraping the wood so as to bring it to its natural state, it has been left very much rougher than new wood freshly planed. It is also proper to call attention to the change which, at the end of a certain time, takes place in the pine-wood bottom of a boat constructed like the "Alma." This bottom undergoes, from the effect of the mechanical and chemical action of the water, a change which we believe is shown by a very rapid wearing and diminution of the thickness. Only the hardest parts, the knots, the fibres, wear less rapidly, and form projections appearing very different from the ends of the wrapping cloth. It is true that the surface of the wood assumes at the same time an unctuous, soapy consistency, which may diminish the friction in a certain degree.

On the contrary, the partial covering with enamelled cloth seems to have a considerable influence. Although it effected only one-third of the wetted surface, it diminished the total resistance at the different velocities, from 12 per cent. to 19 per cent. Such important diminutions arising from the single fact of having substituted upon 31 per cent. of the wetted surface, the enamelled cloth — that is to say, a perfectly smooth surface for the wood brought to its natural state (*i.e.*, a surface passably rough) — seem to show the great importance of the friction of the water against the hull of the boat,— to the *resistance of surface*, in a word.

To completely elucidate the question, we have made a new experiment with the "Alma" entirely covered with enamelled cloth. The results are shown in the following table where the total resistances of the "Alma" are shown: first, with the sides brought to their natural state; secondly, entirely covered with enamelled cloth:—

Designation of the Velocities.	Total Resistance of the Alma.		Diminution.	
	Hull scraped.	Entirely covered with Enamel-cloth.	Absolute.	Relative.
Velocity of 0.50 m.	54 kg.	28 kg.	26 kg.	0.48
Velocity of 1.00 m.	162 kg.	105 kg.	57 kg.	0.35
Velocity of 1.50 m.	355 kg.	250 kg.	105 kg.	0.30
Velocity of 2.00 m.	664 kg.	480 kg.	184 kg.	0.28
Velocity of 2.50 m.	1,119 kg.	812 kg.	307 kg.	0.27

The great importance of the surface resistance is here demonstrated, thus:—at the depth of 1.60 metres and the velocity of 1.50 metres per second, for example, the total resistance of the "Alma" was reduced 30 per cent. by the simple fact of substituting for the passably rough surface of the hull, (wood brought to its natural state), a perfectly smooth surface (enamelled cloth). As, on the other hand, the friction upon the enamelled cloth, although extremely slight, is not absolutely nothing, we may conclude that, *in the assumed conditions of draught and velocity*, the resistance due to the *friction of the water upon the hull, in its natural state, is at least one-third of the total resistance.*

We have not sought to carry farther the analysis of the phenomena of which the surface resistance is the result. We consider it sufficient to have shown the importance of the premium assured to constructors and navigators who will know how to obtain and maintain the smoothness of the wetted surface of the hulls.

At the same time there is a point upon which we have strongly desired to throw light. It is the effect upon the total resistance to traction of substituting an iron hull for a wooden one. Unfortunately, we have not yet succeeded in finding two boats, one of wood and the other of iron, presenting such a complete identity of dimensions and forms that we might certainly attribute the differences which would take place in the curves of total resistance to the difference in the nature of the surfaces. This is an experiment which we shall not fail to make finally.

IV. Influence of the Length.

We have experimented with three boats of the *flûte* type, the "Alma," the "René," and the "Adrien," having the same width at the midship section, 5.02 metres, having fore and aft as identical forms as possible, only differing in length. At the draught of 1.60 metres, at which these experiments were made, the length of the immersed portion of the hull was:—

For the "Alma" . . . . 37.99 m.
For the "René" . . . . 30.03 m.
For the "Adrien" . . . . 20.55 m.

The three total resistance curves obtained are identical, which is shown in examining the following table which gives the resistances at the typical velocities:—

Designation of the Boats.	Resistances at the Successive Velocities.				
	0.50 m.	1.00 m.	1.50 m.	2.00 m.	2.50 m.
Alma, ...	54 kg.	162 kg.	355 kg.	664 kg.	1,119 kg.
René, ...	51 kg.	160 kg.	355 kg.	665 kg.	1,120 kg.
Adrien, ...	51 kg.	160 kg.	355 kg.	665 kg.	1,120 kg.

Hence the three boats present the same resistance to traction; an equal effort is required with a flotation length of 20.55 metres or the "Alma," with a flotation length of 37.99 metres; that is, with a displacement almost double.*

This result seems at first paradoxical, and in entire contradiction to the resistance of surface previously demonstrated; but it is easily explained, if, conformably to the ideas of Du Buat, we admit that the resistance properly called the *resistance of form* is equal to the sum of the *live pressures*

*With the depth of 1.60 metres, the displacement of the "Adrien" is 150 tons, and that of the "Alma" 290.

exercised on the bow of the boat and the *non-pressure* exerted at the stern, the first independent of the length, the second varying inversely as this length, or rather with the ratio of this length to that of the breadth of beam.

Considering the forms of the "Alma," the "René," and the "Adrien" identical, the live pressure is the same for the three; but, for shorter boats, the *non*-pressure is greater, and consequently, also, the resistance of form. We may therefore admit that for these boats the increase in the resistance of form, arising from the shorter length, is compensated by the diminution in the resistance of surface, resulting from the same cause.

This explanation appears very plausible; it is, besides, confirmed by the results of other experiments made under similar conditions. We may therefore consider it demonstrated that, *other things being equal, the resistance of form varies inversely with the ratio of the length of the boat to its breadth of beam,* $\frac{L}{l}$.

V. Influence of the Form.

From what precedes it is evident that, in order to demonstrate the influence of form, we must compare the results of experiments made with boats having as nearly as possible, the same length, width, draught, and condition of surface.

We have united in the following table both the data and the results of the experiments relative to five boats satisfying the above conditions, and belonging: —

Two, the "Dalila" and the "Ourouki," to the type called *péniche* (Plate I.).

Two, the "Alma" and the "Pour nous," to the type called *flûte* (Plate I.).

One, the "Désirée," to the type called *toue* (Plate I.).

The sketches in Plates I. and II. give a sufficiently exact idea of the forms of these different types.

This table shows the inferiority of the type *péniche* and the superiority of the type *toue:* in reality, at the velocity of 1.50 metres for example, the tractive effort required for the *péniche* being 1.00, that required for the *flûte*

Dimensions of the Boats and Resistance to Traction.	Designation of the Boats experimented upon.				
	Péniches.		Flûtes.		Toue.
	Dalila.	*Ourouki.*	*Alma.*	*Pour nous*	*Désirée.*
Dimensions of the immersed part:					
L. Length, ...	38.16 m.	38.00 m.	37.99 m.	36.70 m.	37.76 m.
l. Breadth of beam, ...	5.00 m.	4.97 m.	5.02 m.	5.02 m.	5.03 m.
Ratio: $\frac{L}{l}$, ...	7.64	7.64	7.57	7.31	7.51
t. Draught, ...	1.60 m.	1.60 m.	1.60 m.	1.60 m.	1.60 m.
d. Coefficient of displacement, . .	0.990	0.990	0.950	0.942	0.966
D. Displacement, ...	302 cu. m.	299 cu. m.	290 cu. m.	278 cu. m.	294 cu. m.
Total resistance at the velocity of:					
0.50 m. per second, ...	102 kg.	106 kg.	54 kg.	51 kg.	44 kg.
1.00 m. per second, ...	301 kg.	305 kg.	162 kg.	153 kg.	126 kg.
1.50 m. per second, ...	682 kg.	694 kg.	355 kg.	333 kg.	266 kg.
2.00 m. per second, ...	1,287 kg.	694 kg.	664 kg.	619 kg.	484 kg.
2.50 m. per second, ...	1,287 kg.	694 kg.	1,119 kg.	1,040 kg.	806 kg.
Resistance per cubic metre (or ton) of displacement at the velocity of:					
0.50 m. per second, ...	0.337 kg.	0.354 kg.	0.186 kg.	0.184 kg.	0.151 kg.
1.00 m. per second.	0.996 kg.	1.020 kg.	0.558 kg.	0.552 kg.	0.430 kg.
1.50 m. per second, ...	2.251 kg.	2.321 kg.	1.224 kg.	1.202 kg.	0.907 kg.
2.00 m. per second, ...	4.261 kg.	2.321 kg.	2.289 kg.	2.235 kg.	1.646 kg.
2.50 m. per second, ...	4.261 kg.	2.321 kg.	3.858 kg.	3.755 kg.	2.750 kg.
Resistance at the velocity of 1 metre per square metre of immersed midship section, ...	37.6 kg.	38.4 kg.	20.2 kg.	19.0 kg.	15.7 kg.

is exactly 0.50, and that for the *toue* is less than 0.39. The superiority of the type *toue* even over the type *flûte* is more remarkable, as the *flûtes* are not only sharper at the bow, but have also certain curved forms astern, while the *toues* have only these curved forms at the bow, and have the stern absolutely square. The influence of the elevation of the bottom at the ends was, therefore, preponderant.

In order to further elucidate this point, we have compared, experimentally, the boat "Suffren" of the type called *margotat* (Plate II.) and the *flûte* "Adrien," having the same length and breadth. The following tables show in detail the dimensions of the immersed part of the two hulls, at the common maximum draught of 1.30 metres, of which the *margotat* was capable: —

Dimensions of the Immersed Part.	Adrien.	Suffren.
L. Length, ...	20.25 m.	20.30 m.
l. Breadth of beam, ...	5.02 m.	5.00 m.
Ratio: $\frac{L}{l}$, ...	4.03	4.06
t. Draught, ...	1.30 m.	1.30 m.
d. Coefficient of displacement, ...	0.910	0.818
D. Displacement, ...	120 cu. m.	108 cu. m.

The results of these experiments are shown separately.

In order to render them more striking, we have united them in the same table with those given by the *toue* "Désirée" and the *flûte* "Alma," the dimensions of which are, so to speak, identical.

Resistance to Traction.	Flute and Tone Draught of 1.60 m.				Flute and Margotat Draught of 1.30 m.			
	"Flûte Alma."	"Toue Désirée."	Diminution for the Toue.		"Flûte Adrien."	"Margotat Suffren."	Diminution for the Margotat.	
			Absolute.	Relative.			Absolute.	Relative.
Total at the velocity of:								
0.50 m. per second,	54 kg.	44 kg.	10 kg.	0.185	45 kg.	28 kg.	17 kg.	0.378
1.00 m. per second,	162 kg.	126 kg.	36 kg.	0.222	143 kg.	72 kg.	71 kg.	0.497
1.50 m. per second,	355 kg.	266 kg.	89 kg.	0.251	314 kg.	140 kg.	174 kg.	0.554
2.00 m. per second,	664 kg.	484 kg.	180 kg.	0.271	576 kg.	239 kg.	337 kg.	0.585
2.50 m. per second,	1,119 kg.	806 kg.	313 kg.	0.280	950 kg.	377 kg.	573 kg.	0.603
Per ton of displacement at the velocity of:								
0.50 m. per second,	0.186 kg.	0.151 kg.	0.035 kg.	0.188	0.375 kg.	0.259 kg.	0.116 kg.	0.309
1.00 m. per second,	0.558 kg.	0.430 kg.	0.128 kg.	0.229	1.192 kg.	0.667 kg.	0.525 kg.	0.440
1.50 m. per second,	1.224 kg.	0.907 kg.	0.317 kg.	0.259	2.617 kg.	1.296 kg.	1.321 kg.	0.505
2.00 m. per second,	2.289 kg.	1.646 kg.	0.643 kg.	0.281	4.800 kg.	2.213 kg.	2.587 kg.	0.539
2.50 m. per second,	3.858 kg.	2.750 kg.	1.108 kg.	0.287	7.917 kg.	3.491 kg.	4.426 kg.	0.559

From the figures inscribed in this table, the elevation of the stern doubles, so to speak, the advantages already obtained by the raising at the bow. At the velocity 1.50 metres, for example, the tractive force for the *margotat* is only 45 per cent. of that of the *flûte.*

These results are also confirmed by a final experiment made with the boat "Remesch," of the type called *prussien* (Plate II.). In length and displacement, this boat is sensibly intermediate between the two *flûtes* "Alma" and "René." The first following table shows in detail the dimensions of the immersed part of the three hulls, with the common draught of 1.30.

DIMENSIONS OF THE IMMERSED PART.	ALMA.	RENE.	REMESCH.
L. Length, ...	37.74 m.	29.86 m.	34.10 m.
l. Breadth of beam, ...	5.02 m.	5.02 m.	4.91 m.
Ratio: $\frac{L}{l}$, ...	7.52	5.77	6.94
t. Draught, ...	1.30 m.	1.30 m.	1.30 m
d. Coefficient of displacement, . . .	0.954	0.938	0.935
D. Displacement, ...	235 cu. m.	183 cu. m.	203 cu. m.

In the second table below, we have united the results of the experiments made with the three boats, and compared the figures obtained for the "Remesch" with the mean of those given by the two others. The "Alma" and the "René" having identical total resistances, the mean only presents an interest for the resistances per ton of displacement.

Resistance to Traction.	Flutes.			Remesch.	Diminution.	
	Alma.	René.	Mean.		Absolute.	Relative.
Total at the velocity of:						
0.50 m. per second, . .	44 kg.	45 kg.	44.5 kg.	22 kg.	22.5 kg.	0.506
1.00 m. per second, . .	143 kg.	143 kg.	143 kg.	80 kg.	63 kg.	0.441
1.50 m. per second, . .	315 kg.	314 kg.	314.5 kg.	185 kg.	129.5 kg.	0.411
2.00 m. per second, . .	579 kg.	576 kg.	577.5 kg.	349 kg.	228.5 kg.	0.396
2.50 m. per second, . .	953 kg.	950 kg.	951.5 kg.	582 kg.	369.5 kg.	0.388
Per ton of displacement at the velocity of:						
0.50 m. per second, . .	0.187 kg.	0.246 kg.	0.212 kg.	0.108 kg.	0.104 kg.	0.491
1.00 m. per second, . .	0.609 kg.	0.781 kg.	0.695 kg.	0.394 kg.	0.301 kg.	0.433
1.50 m. per second, . .	1.340 kg.	1.716 kg.	1.528 kg.	0.911 kg.	0.617 kg.	0.404
2.00 m. per second, . .	2.464 kg.	3.148 kg.	2.806 kg.	1.719 kg.	1.087 kg.	0.387
2.50 m. per second, . .	4.055 kg.	5.191 kg.	4.623 kg.	2.867 kg.	1.756 kg.	0.380

At the velocity of 1.50 metres, the effort of traction for the "Remesch" is only 0.59 of that of the *flûtes*.

VI. Conclusions.

It is now possible to form practical conclusions from the point of view of the improvements to be made in the construction of boats used to navigate alternately the rivers and canals of France.

We have already said that for these boats the length (38.50 metres), the width (5.00 metres), and the maximum draught (1.80 metres) are fixed by the law of Aug. 5, 1879. The only variable elements are the forms at the bow and the stern.

As far as concerns the forms, the experiments related above appear to us decisive. From the point of view of the resistance of traction, *two extremities decidedly raised from the keel of the boat* seem obligatory. Let us see if this arrangement is compatible with other equally important conditions,— sufficient capacity, room enough in the locks, facility for evolution, etc. To illustrate this, we have studied in a purely geometrical way two theoretical types of boats which only differ in the rake of their sterns, and which are shown in Plates III. and IV.

The first type (Plate III.) presents a length of 38.58 metres between the perpendiculars, and one of 33.58 metres between the stem and the stern posts. Through this last, the section is uniform, and rectangular, 5 metres wide and 2.20 metres high.

The two extremities are identical. They have the following longitudinal profile: first, a quarter ellipse, of which the semi-vertical axis is 2.20 metres and the semi-horizontal axis 2.50 metres in length; second, a vertical portion of 0.40 metre corresponding to the rake of the boat.

The length of the immersed part at the depth of 1.80 metres is exactly 38.50 metres, the water lines determined by the horizontal plane drawn from 0.20 to 0.20 metre are all, in the parts beyond the stern post, ellipses, and consequently the horizontal extremities are circular.

The second type (Plate IV.) does not differ essentially from the first, except that, the ellipses following those of the extremities, the longitudinal profiles have their horizontal semi-axis 4.50 metres in length instead of 2.50 metres. The length of the immersed part has a draught of 1.80 metres. 38.50 metres, the length between perpendiculars, is raised to 38.64 metres, and that between the rakes is reduced to 29.64 metres.

The exclusive adoption of these geometrical lines permits a very rapid calculation * of the real displacement and the co-

* Here, for example, is the calculation for the first type.

If we call d the displacement of each extremity at the depth of 1.80 metres, the value of the total displacement is $D = 33.58 \times 5.00 \times 1.80 + 2d = 302.22 + 2d$.

The calculation of D is made, in the usual method, thus: —

Water Line No.	Surface Half-ellipse.	Height of Application.	Volume.
0,	$\frac{1}{2}\pi \times 2.50 \times 0.00 = 0.000$	0.10	0.0000
1,	$1.04 = 4.090$	0.20	0.8180
2,	$1.44 = 5.645$	0.20	1.1290
3,	$1.72 = 6.740$	0.20	1.3480
4,	$1.93 = 7.575$	0.20	1.5150
5,	$2.10 = 8.230$	0.20	1.6460
6,	$2.23 = 8.745$	0.20	1.7490
7,	$2.33 = 9.145$	0.20	1.8290
8,	$2.41 = 9.445$	0.20	1.8890
9,	$2.46 = 9.655$	0.10	0.9655
Total,		$t = 1.80$	$d = 12.8885$

$$D = 302.22 + 2 \times 21.8885 = 327.997 = 328$$

efficient of displacement of each of the two types at the legal draught of 1.80 metres.

For the first type we have,—

$$D = 328^t \; d = \frac{328}{38.50 \times 5.00 \times 1.80} = 0.946;$$

and for the second,—

$$D = 313^t \; d = \frac{313}{38.50 \times 5.00 \times 1.80} = 0.904.$$

If for both extremities of the boat we adopt the form corresponding to either of these two types, or still another intermediate form by maintaining the immersed length at 38.50 metres, we shall certainly have a coefficient of displacement and an intermediate displacement between those calculated above.

There is no doubt, therefore, that we can in practice construct boats capable of navigating canals and satisfying the above-named condition (raking extremities), preserving a coefficient of displacement comprised between 0.90 and 0.95, and a total displacement equivalent to that of the types actually in use; that is, the *péniches.* It seems evident that the use of the iron would facilitate the making of curved extremities without any projection at the stem or stern.*

It may be remarked that the term "spoon" is precisely that used by a celebrated constructor in Germany, Mr. Theodore Klepsch, of Frankfort-on-Oder, author of the first treatise* which was published, we believe, on the construction of boats for river navigation in order to characterize the shape which he recommends giving to the ends of boats so as to obtain the best nautical qualities.

Guided by the experience acquired during long years of practice, and by the success obtained by the boats built in his yards, Mr. Klepsch arrives at this conclusion: that boats intended for river navigation should be spoon-shaped at their two extremities.

* Der Fluss-Schiffsbau, von Th. Klepsch. Weimar, 1889. Bernhard Friedrich Voigt.

After three years of experimental researches on river boats, conducted without any preconceived idea, and in reference principally to their variations in resistance to traction, we arrive at an identical conclusion.

This fact appears worthy of being noted.

However, we can, in conclusion, strike a balance between the advantages and the disadvantages presented by those whose geometric form we have sketched above in respect to the "*péniches*" which form the majority of boats capable of alternate navigation on the canals and rivers of France.

As disadvantages, we have only to note the sacrifice made for the sake of their form. It is not excessive, varying according to the type from 4.4 per cent. to 8.6 per cent., corresponding respectively to from 15 to 30 tons' reduction on a total displacement of 350.

As advantages independent of the very superior nautical qualities, and discounting the possible benefit in the substitution of iron for wood, we may put into the account *the reduction of the tractive effort, and consequently of the cost of traction upon rivers, to about one-quarter* of what they actually are.*

PARIS, May 25, 1893.

*The tractive effort is for the *prussien* 0.59 and for the *margotat* 0.45 of what it is for the *flûte*; that is, respectively, 0.295 and 0.225 of what it is for the *péniches*.

PLATE 1.

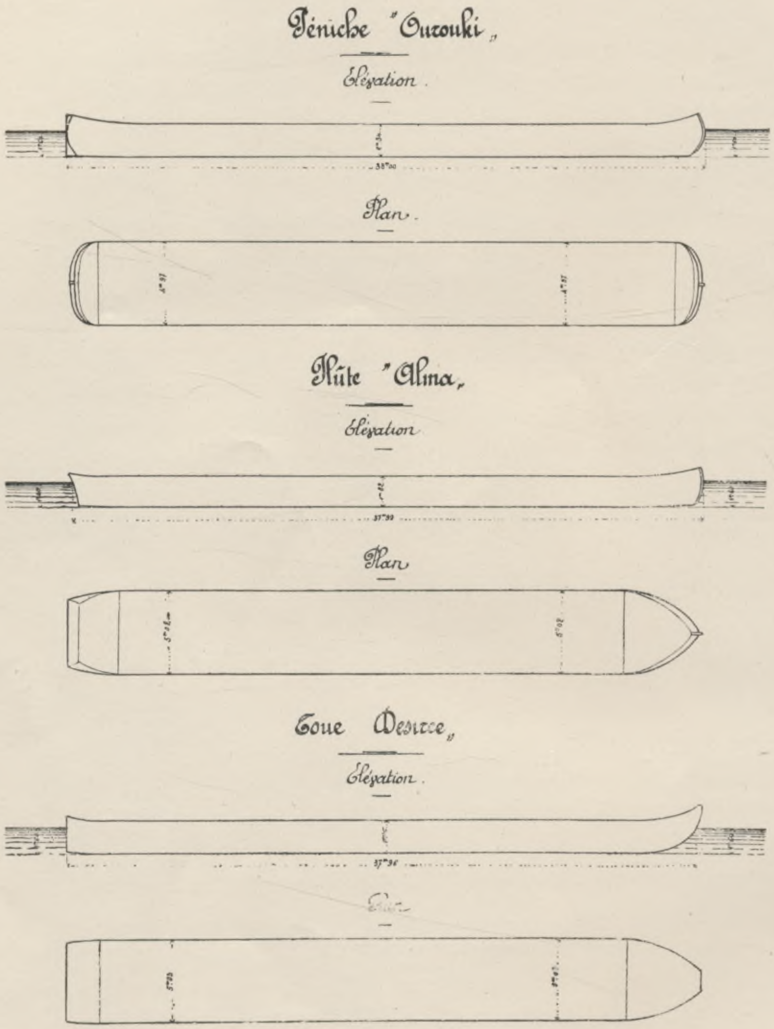
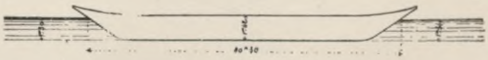

Péniche "Ourouki"
Élévation.
Plan.
Flûte "Alma"
Élévation
Plan
Toue Désirée"
Élévation.

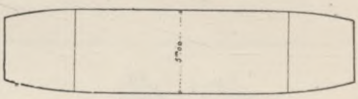
PLATE II.

Margotack "Duffen"

Élévation

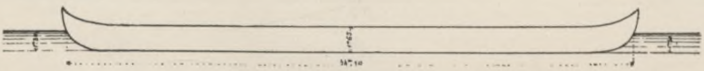


Plan

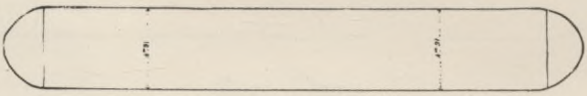


Bateau prussien "Remesch"

Élévation

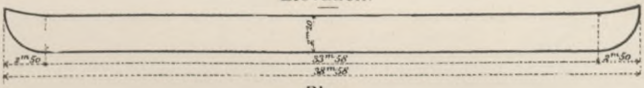


Plan



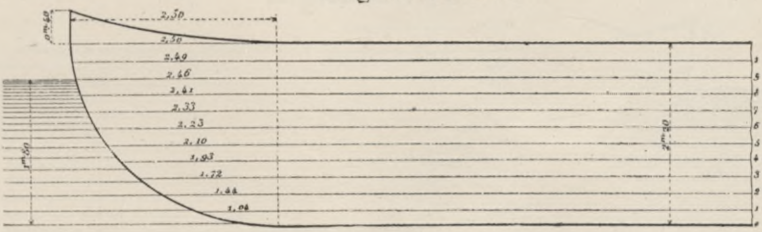
Croquis des bateaux expérimentés

Elévation.



Plan

Longitudinal AV et AR.



Horizontal AV et AR

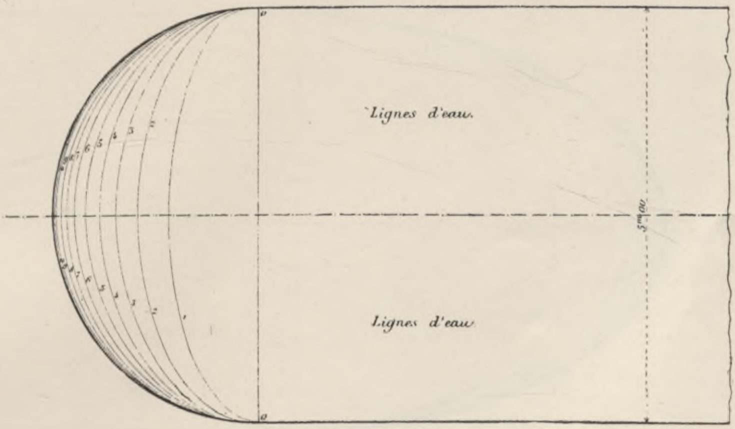
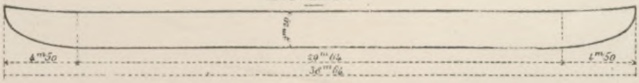
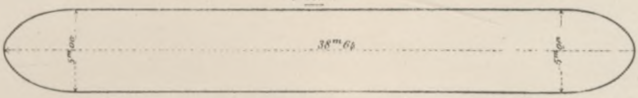


PLATE IV.

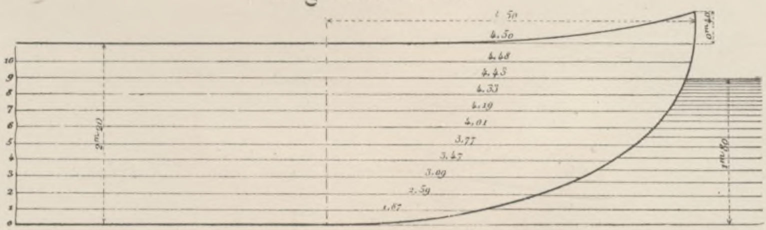
Elévation.



Plan.



Longitudinal A/ et Æ.



Horizontal A/ et Æ.