Thesis.

A. C. Lyon.

J. S. Currier.

Course XIII '04.

M. I. T.

SLOOP FRANCES.

Length overall	24'
Length l. w. l.	21'2"
Beam maximum at deck	9'
Draught maximum	3'2"
Displacement	6500 lbs.
Wetted surface	
at 18° Inclination	167.4 sq. ft.
Sail Area:	
Jib	109 sq. ft.
Mainsail	376 " "
Total	485 " "

66130

An Experimental Determination of the Power Developed by the Sails of a Small Yacht.

These tests were made upon the 21 ft. w. l. jib and mainsail rigged yacht Frances, whose lines, dimensions, and sail-plan are shown in the accompanying tracing. Their object was to determine the power developed by the sails of the yacht.

The method of investigation consisted:-a) in sailing the yacht over the measured course in Nantasket Roads, Boston Harbor, in both directions, carefully measuring the elapsed time, the inclination of the yacht, the velocity and direction of the wind, and actual time of start; and b) in towing the yacht over the same course, at the same stage of the tide, with the corresponding inclinations, and at the same speeds, readings being taken of the elapsed time, the pull on the tow-line, and the actual time of start. The tidal corrections were obtained by measuring the velocity of the tide by a Price electric current meter, loaned by the Civil Engineering Department.

Sailing tests were made every Thursday in October, 1903; for various reasons many were unsatisfactory, and from the total number made, four successive runs, made on October 22nd., were selected as the basis of the experiments. On this day there

was a good whole sail breeze from the southward, so that it was a close reach in against the tide and a broad reach out with the tide. There was very little chop on the course. The first run was made about an hour after high-water.

In order to measure the inclination which the yacht took the following method was used:- Near the foot of the mast a cross-piece, graduated into inches each way from the center, was fixed parallel to the water line; at a point 100 inches above the center of this stick two plumb-bobs were suspended, one on each side, to act as pendulums; then as the pendulum swung out the tangent of the angle of heel could be read directly. The time from range to range over the course was measured by a stop watch; the velocity of the wind was measured by a standard anemometer stationed in a small boat anchored near the middle of the course. Readings of the anemometer and the pendulums were taken at two minute intervals during the runs.

On November 1, 1903 the steamer Guardian, of the Boston police Department, was secured to tow the yacht over the course, the object of this being to find the pull on the tow-line. Care was taken to make the time over the course coincide as nearly as possible with that of the corresponding sailing test. The yacht

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was heeled over to the different angles by swinging several iron weights on one side at the end of the boom. As she had been stripped of sails and other gear, the addition of these weights did not appreciably change her displacement. At each inclination, then, she was towed over the course, presenting the same wetted surface as while sailing. These towing tests were also made about an hour after high water, and the wind, too, happened to be from the same direction as before.

To measure the pull on the tow-line the following device was used;- a rope strap was passed around the mast close to the deck and into each end of it a spring balance was hooked. Through the rings at the other ends of the balances a steel bar was passed, to which the line from the tug was made fast. Then the readings of the springs would give the force necessary to pull the boat, and this multiplied by the distance would be the work done. The balances were afterward calibrated in the wire-testing machine in the Institute Laboratory, and found to read correctly.

In order to obtain the displacement and wetted surface of the yacht, it was necessary to obtain her lines. This was done, as soon as the ice and snow were gone, in the following manner.

A datum plane was first established beneath the boat by laying two long planks parallel to the keel, one close in to the keel, the other about four feet out from it on the same side, the plane of the upper surfaces of the planks being made level in all directions,(as the ground beneath her was very nearly level, the yacht was on an even keel.) The length of the boat was then divided into stations, spaced equally, except in one place where the blocking interfered. A graduated cross-piece, reading from the center-line of the keel was placed at each station successively. Then by holding a plumb-line to the skin of the yacht at any point and reading the abscissa on the stick and measuring the plumb-line for the ordinate, that point could be located. In this way the coordinates of from four to six points at each station were obtained. Other measurements were also taken, as the freeboard fore and aft, overhangs, length overall and on the water-line, sizes of spars, sails, & etc. The results were then plotted and the lines of the yacht faired up in the usual way. From the lines the displacement was figured, and the wetted surface at each different inclination was determined. For the latter Taylor's method was used, and care was taken to see that the displacement was kept constant.

The displacement of the yacht as figured from the lines, is 6500 lbs. The difference between the wetted surfaces at the three inclinations used, 16°30', 18°, and 22°20' is only 1 in the fourth place, which is probably within the errors of the work. The wetted surface may then be considered constant at 167 sq. ft. The sail area is 485 sq. ft.

From the data obtained from the towing tests two curves were plotted, No. 1, with horse-powers for ordinates and velocity in knots per hour as abscissae, and No. 2, with the same velocities for abscissae, and resistance per sq. ft. of wetted surface for ordinates. Then the ordinates were drawn at the speeds obtained during the sailing tests, and the ordinates of the points where these lines cut the curves gave the power developed by the sails and the resistance offered by the skin of the boat. It was necessary to exterpolate the curves to the point of 6.28 knots, as the towing test made at this speed (Test No. 5.) is evidently not to be relied on, it giving only 2.39 H. P. as the work done in towing the yacht at this the highest speed. Possibly a rope jammed somewhere.

All the data, calculations, and results are found in the following tables and drawings.

TABLE.

Velocity Knots per hr.	Tow Line Resistance	Thrust H. P.	Resistance per sq. ft. W.S.	Eff. Thrust. per sq. ft. of Sail.
5.34	88.5 lbs.	1.45	0.53 lbs	0.18 lbs.
5.71	100	1.75	0.59	0.206
5.98	261	4.8	1.55	0.54
6.08	297.7	5.56	1.77	0.61
6.13	322	6.05	1.92	0.66

Curves plotted from the values in the above table will be found on Plate 1.

Erecting ordinates to the curve of horsepower at the proper points gives the following values for the Thrust Horse Power developed by the sails.

At 5.62 knots H. P. = 1.59

" 5.78 " H. P. = 2.09

" 6.28 " H. P. = 7.59

WETTED SURFACE.

Calculated from lines by the method of Naval Constructor Taylor.

At 16° 30' Inclination Wetted Surface = 167.3 sq. ft.

At 18° " " " = 167.4 " "

At 22°20' " " " = 167.2 " "

TABLE

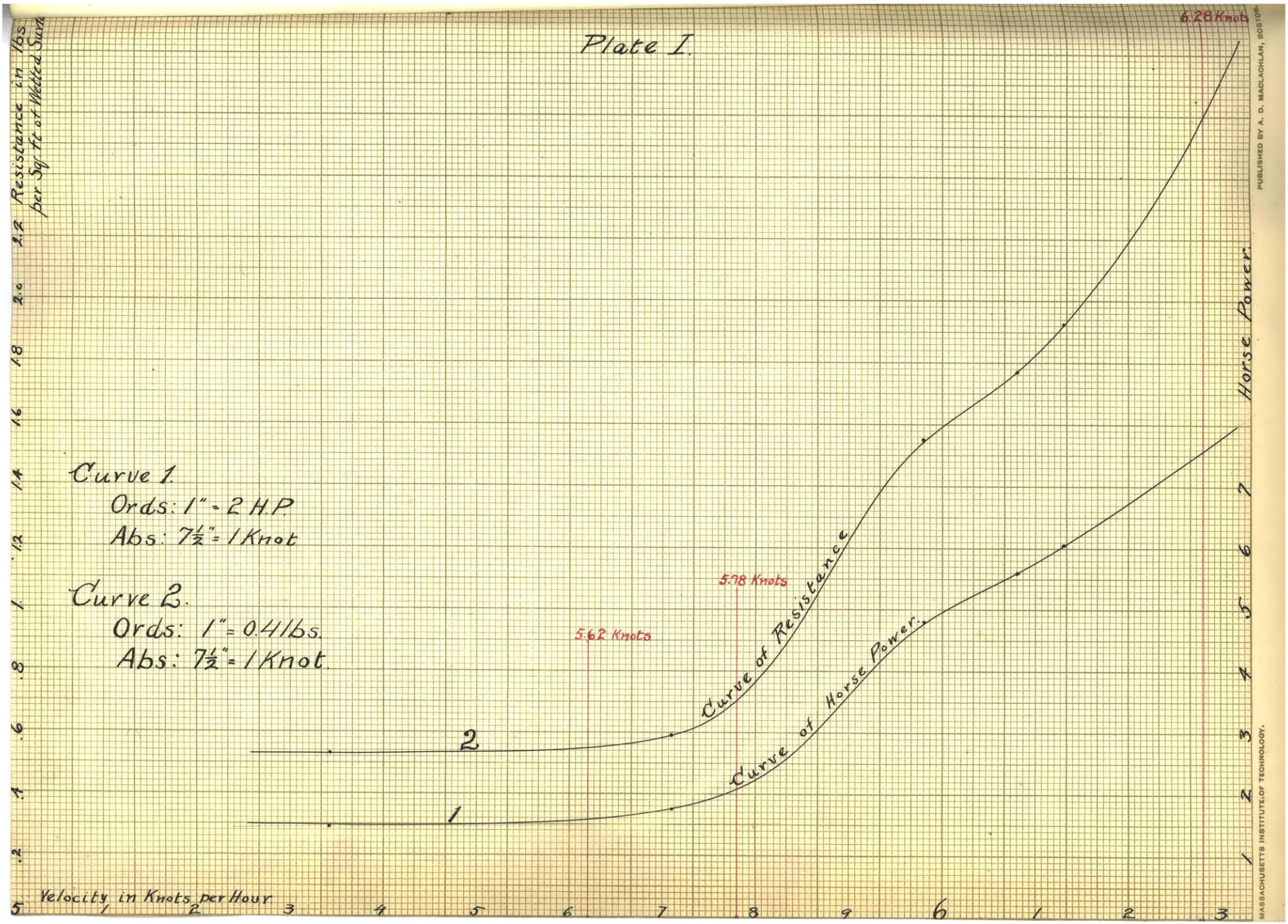
of

Resistance Per Sq. Ft. of Wetted Surface.

Velocity. Knots Per Hour.	Resistance. lbs.
5.34	0.53
5.71	0.59
5.98	1.55
6.08	1.77
6.13	1.92

Speed of wave 21'2" long, 2.03' per second
= 1.2 knots per hour.

Plate I.



Oct. 22, 1903.

Run No. 1. Close hauled on port Tack.

High tide at 12:20 P. M.

Mean hight of tide at Navy Yard 11.1.

Course W. S. W. Against the tide.

Av. Vel. of wind by Anemometer = 17.22 miles per hour.

Av. Vel. of tide by Exp. = 1.57 knots = 159 ft. per min.

Av. Vel. of tide by tide tables= 1 knot N.64° E.

Av. Inclination of yacht-------= $\tan^{-1}$ .41 = 22°20'

Time of start = ----------1:47:20 P. M.

Elapsed time over course = --0:13:52 4/5

Speed of yacht = ----------4.05 knots.

" " " (corrected for tide) = 5.62 knots.

" " " in feet per minute = 567 ft. per min.

Length of course = 0.9335 knots = 5675.7 feet.

High tide 12:20 o'clock P. M.

Anemometer Readings.

Time.	Read.	Diff.	Inclination Readings.
1:46	3766.83		41
1:48	3767.42	0.59	40
1:50	3768.00	0.58	40
1:52	3768.55	0.55	42
1:54	3769.25	0.70	42
1:56	3769.76	0.51	41
1:58	3770.32	0.56	6) 246
2:00	3770.81	0.49	41 Av.
2:02	3771.42	0.61	

Sum = 4.59 in 16 min.

Av.= 0.57 3/8 = 0.28 11/16 knots per min.

Oct. 22, 1903.

Run No. 2. Wind free on Starboard Tack.

Course E. N. E. With tide.

Av. Vel. of wind by Anemometer = 18.48 miles per hour.

Av. Vel. of tide by Experiment = 1.57 knots = 159 ft. per min.

Av. Vel. of tide by Tables = 1.1 knots = N 64°E.

Av. Inclination of Yacht = $\tan^{-1}$ 0.348 = 18°00'

Time of Start ---------- = 2:05:00 P. M.

Elapsed time over course ----- = 7:10

Speed of Yacht ---------- = 7.85 knots.

Speed of Yacht (corrected for tide) = 6.28 knots.

Speed of Yacht in ft. per min. ---- = 634

Length of Course ---------- = 0.9335 knots = 5675.7 ft.

Anemometer Readings.

Time.	Read.	Diff.	Inclination Readings.
2:04 --	3772.05		38
2:06 --	3772.61 --	0.56	41
2:08 --	3773.35 --	0.74	41
2:10 --	3773.99 --	0.64	38
2:12 --	3774.60 --	0.61	23
2:14 --	3775.23 --	0.53	28
		Sum =3.08	6)209
			AV.=34⅞

Av. =0.616 = 0.308 per min.

Oct. 22, 1903.

Run No. 3. Close hauled on port Tack.

High tide at Navy Yard at 12:20 P. M.

Mean height of tide by table = 11.1 ft.

Course W. S. W. Against the tide.

Av. Vel. of wind by Anemometer = 16.80 miles per hour.

Av. Vel. of tide by Experiment = 1.57 knots = 159 ft. per min.

Av. Vel. of tide by Tables = 1.1 knots N 64°E.

Av. Inclination of Yacht = $\tan^{-1}$ .41 = 22°20'

Time of start---------- = 2:15 P. M.

Elapsed time over course ----- = 13 min. 21 1/5 sec.

Spped of Yacht ---------- = 4.21 knots.

" " " (corrected)-- = 5.78 knots.

" " " in ft. per min.-- = 584.

Length of course = 0.9335 knots, = 5675.7 ft.

Anemometer Readings.

Time.	Read.	Diff.	Inclination Readings.
2:14 ---	3775.23		38
2:16 ---	3775.79	-- 0.56	40
2:18 ---	3776.39	-- 0.60	42
2:20 ---	3776.97	-- 0.58	41
2:22 ---	3777.50	-- 0.53	44
2:24 ---	3778.05	-- 0.55	41
2:26 ---	3778.57	-- 0.52	6)246
2:28 ---	3779.12	-- 0.55	Av.=41
2:30 ---	3779.71	-- 0.59	

8)4.48

0.56 = 0.28 per min.

Oct. 22, 1903.

Run No. 4. Wind free on starboard tack.

Course E. N. E. With the tide.

Av. Vel. of Wind by Anemometer = 18.18 miles per hour.

Av. Vel. of Tide by Experiment = 1.57 knots = 159 ft. per min.

Av. Vel. of Tide by Tables = 1.1 knots N. 64° E.

Av. Inclination of Yacht ------ = $\tan^{-1}$.296 = 16° 30'

Time of Start ---------- = 2:35 P. M.

Elapsed time over Course ------ = 7 m. 10 sec.

Speed of Yacht ---------- = 7.85 knots.

Speed of Yacht (corrected for tide) = 6.28 knots.

Speed of Yacht in feet per min. = 634

Length of Course ---------- = 0.9335 knots = 5675.7 ft.

Anemometer Readings.

Time	Read.	Diff.	Inclination Readings.
2:31	3783.63		34
2:33	3784.25	0.62	25
2:35	3784.77	0.52	33
2:37	3785.37	0.60	28
2:39	3786.08	0.71	28
2:41	3786.67	0.59	6) 148
2:43	3787.27	0.60	Average = 296
	Sum	= 3.64	
	Av.	= 0.607 = 0.303 per min.	

Towing Test. No. 1.

Nov. 1, 1903. 9:59 A. M.

High Tide at 8:12 A. M.

Course W. S. W. Against the tide.

Elapsed time ---------- 13 min 31 3/8 sec.

Av. Vel. of tide by Tables -------= 1.1 knots N 64° E.

" " " " " Experiment --- = 1.57 knots = 159 ft. per min.

" Inclination of Yacht ---------- = 22°20'

Inclining Moment ---------- = 4552 ft. lbs.

Speed of Yacht ---------- = 4.144 knots = 4.77 miles per hour.

" " " (corrected for tide)--= 5.74 knots.

" " " in ft. per minute --- = 420. corrected = 579 ft. per min.

Length of Course = 0.9335 knots = 5675.7 ft.

Average pull on tow line ------ = 100 lbs.

Power Required to Tow Yacht = 57900 ft. lbs. per min.

H. P. required ---------- = 1.75

Dynamometer Readings.

No. 4.	No. 1.	
80 lbs.	20 lbs.	
80	20	
80	20	75
80	30	25
80	30	100 lbs.
80	20	
60	30	
60	30	
8)600	8)200	
75 lbs.	25 lbs.	

Inclining Moment = 3672+240+640 = 4552 ft. lbs.

Towing Test. No. 2.

Nov. 1, 1903. 10:29 A. M.

Course E. N. E. Tide Free.

Elapsed Time = 7 min. 17 sec.

Av. Vel. of Tide by Tables = 1.15 knots N 60° E.

" " " " " Experiment= 1.57 knots = 159 ft. per sec.

Inclination of Yacht = $\tan^{-1}.30$ = 16°30'

Inclining Moment = 3672 ft. lbs.

Speed of Yacht = 7.70 knots = 8.87 miles per hour.

" " " (corrected) = 6.13 knots.

" " " in ft. per min. = 620

Length of Course = 0.9335 knots = 5675.7 ft.

Average pull on Tow Line = 322 lbs.

Power required to Tow Yacht = 199640 ft. lbs. per min.

" " " " " = 6.05 H. P.

Pull on Tow Line.

Balance No. 4.	Balance No. 1.	
200 lbs	100 lbs.	
240	130	212
220	120	110
200	100	322 lbs.
200	100	
5)1060	5)550	
212	110	

Inclining moment =

$$16.08 \times \frac{3.625}{3.75} \times \frac{2.96}{3} \times 80 \times 3 = 3672 \text{ ft. lbs.}$$

Towing Test. No. 3.

Nov. 1, 1903. 10:46 A. M.

Course W. S. W. Against Tide.

Elapsed Time = 14 min. 51 1/5 sec.

Av. Vel. of Tide by Tables = 1.15 knots = N 60° E.

" " " " " Experiment = 1.57 knots = 159 ft. per min.

Inclination of Yacht -------- = $\tan^{-1}$.41 = 22° 20'

Inclining Moment ---------- = 4552 ft. lbs.

Speed of Yacht = 3.77 knots = 4.27 miles per hour.

" " " (corrected) = 5.34 knots.

" " " in ft. per min. = 382, Corrected = 541 ft, per min.

Length of Course = 0.9335 knots = 5675.7 ft.

Average pull on Tow Line = 88.5 lbs.

Power required to Tow Yacht = 47879 ft. lbs. per min.

" " " " " = 1.45 H. P.

Pull on Tow Line.

Balance No. 4.	Balance No. 1.	
60	20	
60	20	
60	30	61.4
70	30	27.1
60	30	88.5
60	30	
60	30	
7)430	7)190	
61.4	27.1	

Inclining Moment =

3672 ft. lbs +240 ft. lbs.+2 X 80 X 4 = 4552 ft. lbs.

Towing Test. No. 4.

Nov. 1, 1903. 11:08 A. M.

High tide at 8:12 A. M.

Course E. N. E. Tide Free.

Elapsed Time = 7 min. 24 3/5 sec.

Av. Vel. of Tide by Tables = 1.2 knots N 60°E.(True)

" " " " " Experiment = 1.57 knots = 159 ft. per Min.

Inclination of Yacht = $\tan^{-1}$ .35 = 18°00'

Inclining Moment = 3912 ft. lbs.

Speed of Yacht = 7.55 knots = 8.69 miles per hour.

" " " (corrected) = 5.98 knots.

" " " " in ft. per min. = 607

Length of Course = 0.9335 knots = 5675.7 ft.

Average Pull on Tow Line = 261 lbs.

Power required to Tow Yacht = 158427 ft. lbs. per min.

" " " " " = 4.8 H. P.

Pull on Tow Line.

Balance No. 4.	Balance No. 1.	
220	120	
200	100	
180	90	
200	100	
160	80	175
150	80	86
		261 lbs.
140	60	
150	60	
8)1400	8)690	
175	86	

Inclining Moment =

3672 ft. lbs +2 X 80 X 1.5 = 3912 ft. lbs.

Towing Test. No. 5.

Nov. 1, 1903. 11:25 A. M.

Course W. S. W. Against Tide.

Elapsed Time = 12 min. 5 4/5 sec.

Av. Vel. of Tide by Tables = 1.2 knots N 60° E.

" " " " " Experiment = 1.57 knots = 159 ft. per min.

Inclination of Yacht = 16° 30'

Inclining Moment = 3672 ft. lbs.

Speed of Yacht = 4.63 knots = 5.33 miles per hour.

" " " (corrected) = 6.20 knots.

" " " in Ft. per min. = 469, corrected = 628 ft. per min.

Length of Course = 0.9335 knots = 5675.7 ft.

Average Pull on Tow Line = 125.6 lbs.

Power required to Tow Yacht = 78876.8 ft. lbs. per min.

" " " " " = 2.39 H. P.

Pull on Tow Line.

Balance No. 4.	Balance No. 1.	
80	30	
100	50	
90	50	
80	40	84.2
80	40	41.4
80	40	125.6
80	40	
7)590	7)290	
84.2	41.4	

Inclining Moment =

$$16.08 \times \frac{3.625}{3.75} \times \frac{2.96}{3} \times 80 \times 3 = 3672 \text{ ft. lbs.}$$

Towing Test. No. 6.

Nov. 1, 1903. 11:41 A. M.

Course E. N. E. With Tide.

Elapsed Time 7 min. 18 3/5 sec.

Av. Vel. of Tide by tables = 1.2 knots = N 60°E.

" " " " " Experiment = 1.57 knots = 159 ft. per min.

Inclination of Yacht = $\tan^{-1}$ .35 = 18°00'

Inclining moment = 3912 ft. lbs.

Speed of Yacht = 7.65 knots = 8.80 miles per hour.

" " " (corrected) = 6.08 knots.

" " " " in ft. per min. = 617

Length of Course = 0.9335 knots = 5675.7 ft.

Average pull on Tow Line = 297.7 lbs.

Power Required to Tow Yacht = 183681 ft. lbs. per min.

" " " " " = 5.56 H. P.

Pull on Tow Line.

Balance No. 4.	Balance No. 1.	
240	130	
240	150	
220	130	
180	100	
170	90	191.1
160	80	106.6
		297.7 lbs.
160	80	
180	100	
190	100	
9)1720	9)960	
191.1	106.6	

Inclining moment =

3672 ft. lbs +2 X 80 X 1.5 = 3912 ft. lbs.

DATA FOR TIDE CORRECTIONS.

APRIL 2, 1904. 2:30--3:00 P. M.

TIDE HIGH AT 12:14 P. M. MEAN HEIGHT 11.1 FT.

STRONG WIND BLOWING WITH TIDE.

Readings of the velocity of the tide were taken with a Price Electric Meter.

The computations were made by aid of a rating table made for this meter by observations on August 18, 1903.

The results are given in the following table:

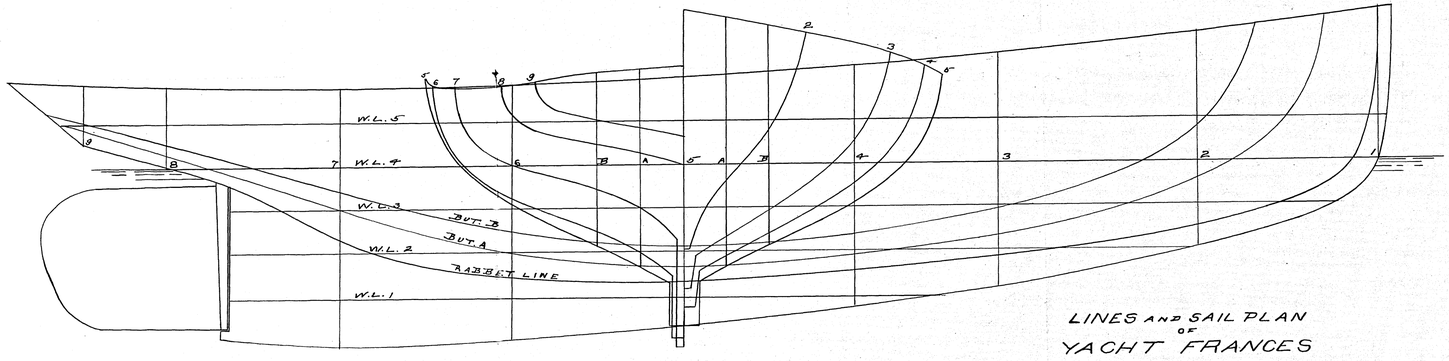
TABLE.

VELOCITY OF TIDE.

Number of trial.	Duration.	Revolutions Total.	Revolutions Per Sec.	Feet Per Sec.	Knots Per Hour.
1	1 min.	67	1.116	2.65	1.57
2	42 2/5 Sec.	50	1.17	2.77	1.64
3	81 1/5 Sec.	100	1.21	2.90	1.71
4	2 min.	134	1.116	2.65	1.57
5	2 min.	144	1.2	2.84	1.68
6	5 min.	392	1.3	3.07	1.82
7	5 min.	470	1.57	3.69	2.18

CALIBRATION OF SPRING BALANCES.

No. 1. Readings.		No. 4. Readings.	
Machine	Balance	Machine	Balance
0	0	0	0
10	10	10	10
20	20	20	20
30	30	30	30
40	40	40	40
50	50	50	50
60	60	60	60
70	70	70	70
80	80	80	80
90	90	90	90
100	100	100	100
110	110	110	110
120	120	120	120
130	130	130	130
140	140	140	140
150	150	150	150
160	160	160	160
170	170	170	170
180	180	180	180
190	190	190	190
200	200	200	200
225	225	225	225
250	250	250	250



LINES AND SAIL PLAN OF YACHT FRANCES

DISPLACEMENT	6500 LBS.
L. O. A.	24 FT.
L. W. L.	21 FT 2 IN.
BEAM	9 FT.
DRAUGHT	3 FT 2 IN.
SAIL AREA	485 SQ. FT.

SCALES $\frac{3}{4}$" = 1 FT. AND $\frac{3}{8}$" = 1 FT.

A. B. Lyon.
J. S. Currier