THESIS

This thesis waa contributed by

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T H E S I S

AN INVESTIGATION OF

STEAM ENGINE

PERFORMANCE.

under

VARIABLE LOAD

MICHIGAN AGRICULTURAL COLLEGE

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By F. C. Taylor and F. E. Wood.

4-51

THE STEAM ENGINE UNDER VARIABLE LOAD.

Object: To determine, experimentally, the relation between variable loads and constant load as to their effect upon steam consumption in steam power installation.

Method: The steam consumption per indicated horsepower per hour for the engine on which the tests were made was carefully determined for a series of constant loads and its characteristic curve plotted as shown. We then selected what seemed to be characteristic load curves of two large power stations, one a lighting plant and one an electric railway power station. (See Plate I). It was not thought feasible to run a full twenty-four hour test for each of these curves but as our determinations were designed to be only relative the scale of time was reduced so that the test could be made in something more than three hours. That is, the twenty-four hour period was reduced to one hundred and ninety-two minutes. The scale of power output was reduced so as to come within the limit of the engine used. With these reduced scales the tests were made as described in detail later. The average value of indicated horsepower and of steam consumption per indicated horsepower hour were plotted upon the sheet containing the characteristic curve for the engine. The difference between the steam consumption ordinate for this horsepower and the ordinate for constant load at the same horsepower should show the effect which was to be determined.

Apparatus: The engine used in these tests is a new Corliss of the Nordberg type built by the Nordberg Construction Company of Milwaukee which was installed in the engine laboratory of this college during the fall of 1908.

Diameter of cylinder		12 inches	
Stroke		30 "	
Diameter of piston rod		2 5/16 "	
Connecting rod	6 ft.	3 "	R/L = 1/5
Fly wheel diameter	10 "		
Brake wheel	6 "		
Main bearing		5 3/4 in. x 9 in.	

Cylinder displacements:

Head end	3393 cu. in. = 1.96 cu. ft.
Crank end	3267 " " = 1.889 " "

Clearance volumes:

Head end	67.83 cu. in. = 2%
Crank end	63.63 " " = 1.94%

Indicated horsepower constants:

Head end	0.0085674
Crank end	0.0082493

Brake horsepower constant 0.001098

Rated revolutions per minute 90.

Indicators: Two indicators were used one for each end. Both, however, were run from the same Crosby reducing motion by attaching a double pulley which carried the cords running around the drums in place of that regularly supplied with the reducing gear. The springs were calibrated (See Table VII) and the proper correction applied to the mean effective pressure.

Calorimeter: A standard make of the Carpenter Throttling Calorimeter was used. The sample steam was taken out of the steam pipe just above the throttle valve.

Thermometer: The thermometer used was compared with a standard instrument and found to be correct in the limits of accuracy within which it could be read.

Scales: All scales used were calibrated and their calibration curves, if any error was noted, are shown herewith. (See Plate III.)

Formulas:

$$I.H.P. = PKN \qquad B.H.P. = WKN$$

Where P = mean effective pressure

K = horsepower constant

N = revolutions per minute

W = brake weights.

$$\text{Quality of steam} = \frac{H + .48\,(t'' - t') - h}{L}$$

Nomenclature is that used in Peabody's steam tables.

Pounds of dry steam per horsepower hour

$$\frac{Q \times W \times 60}{H.P \times T}$$

where

Q = quality of steam

W = weight of condensed steam

$H.P$ = horsepower

T = time in minutes.

The first work was done on Tuesday, March 30th, 1909. We spent the day in getting the engine into shape and rigging up the indicators.

The next day, Wednesday, we found that the cutoff on the crank end was considerably greater than that on the head end and so proceeded to reset the valves to correct this. Wednesday afternoon we were running the engine when the main bearing got hot enough so that the babbitt metal filled the oil grooves in the quarter boxes and cap. We took these parts out, renewed the oil grooves and scraped the bearing to a fit. We experienced no more difficulty from this cause throughout the tests.

Thursday morning was spent in final adjustments of the indicator rig. Thursday afternoon a preliminary run was made for the purpose of testing our apparatus, the engine and auxiliaries and to familiarize ourselves with the method and requirements.

On Friday, April 2nd, our test No. 1 was run.

TEST NO. 1. Made April 2, 1909.

In this test, which was run for seven and a half hours, we used eight loads. The first six were kept constant for fifty minutes each, allowing ten minutes for the brake to take up each new load, and for the air pump etc. to be brought under the new conditions. The seventh load was only applied for ten minutes and was found to be too small for the overload we wished. This was then increased until the cards showed cutoff at about 80% of the stroke. This gave as high an overload as the scale would stand and it was kept constant for fifty minutes.

Cards were taken from each end every ten minutes, and the M. E. P. and I. H. P. were figured in the usual way.

The vacuum was kept constant at 20" as nearly as was possible varying but slightly either way.

The I. H. P. and B. H. P. and quality of steam were figured by means of the formulae given above.

Average values of I. H. P., B. H. P. and pounds of dry steam per horse-power-hour were computed and plotted, as before mentioned, on Plate II. Any point on these curves giving the average steam consumption of the engine if run at that corresponding load.

Characteristic indicator cards were selected from each load and tracings were made of them. Blue prints will be found of these cards under Fig's. 1 and 2. Fig's. 1a -

1h being cards from the head end of the cylinder, and Fig's 2a-2h, being cards from the crank end.

A copy of the running log, or the observed data will be found in Table I, computed data will be found in Table II.

TEST NO. II. Made May 13, 1909.

In this test we followed out the variable load of a Street Railway Power plant, as given by the ampere chart for a day, and which is shown in full line in Plate I. We assumed the peak load of 1,120# on the brake and reduced the ampere scale to correspond to this. Loads were changed every minute of the test and cards and readings were taken every four minutes. Our computations were based on these readings. The condensed steam from the condenser would lag behind a few minutes and when the steam consumption per horse-power-hour was figured from these readings, taken at the same times, we obtained such absurd results as 130 pounds of dry steam per I. H. P. H. So to correct this error we took the average horse power and average steam consumption for the whole test and plotted these on Plate II giving as the average steam consumption for this class of load.

This test was also run with a vacuum of about 20 inches. The air pump stopped at the peak load for about a minute but the vacuum only changed to seventeen inches.

At time there appears to be a discrepancy between the I. H. P. and B. H. P. sometimes the I. H. P. being less than the B. H. P. This is probably due to the fact that the load was decreasing and the brake had not been entirely adjusted to the new load. While running at the minimum load the cylinder did not take steam at every revolution, this gave a negative horsepower at times, cards taken at this time are shown in Fig's. 3b and 4b. Cards for maximum load are shown at 3a and 4a, and cards taken at the minimum load when the cylinder was taking steam are shown in Fig's. 3c and 4c. Fig's. 3a-3c being head end cards and 4a-4c being crank end cards.

A copy of the running log or observed data will be found in Table III, computed data in Table IV.

TEST NO III. Made May 18, 1909.

In general this test was run and worked up as No. II had been. The load used however, was that of an Electric Lighting plant. Plotted as shown in broken line of Plate I.

Both the peak and minimum loads of this test were higher than those of No. II. The average load being at the most efficient load as shown by the steam consumption curves of test No. I.

The average H. P. and steam consumption are shown on Plate II.

Fig's 5a and 5b are cards from the head end taken at maximum and minimum loads respectively. Fig's. 6a and 6b are cards from the crank end taken simultaneously with 5a and 5b.

A copy of the running log or the observed data will be found in Table V; the computed data in Table VI.

(Fig's. 7 and 8 are cards taken just as we were starting this test, before the steam was entirely turned on. These show the action of this type of Corliss valve. It allows the cylinder to receive steam its full stroke when starting.)

Conclusion: The tests show conclusively that the effect of considerable variation in loads during the day is to increase the steam consumption largely. Although the method of applying the results of our test might be questioned by some as being inaccurate yet we are very sure that any inaccuracies due to this cause would show only a possible variation in the amount of the increase as shown by our Plate II and would not affect our conclusion. An interesting point for further investigation would be the economic limit to which the increase in the number of power units employed might be carried in reducing the unit steam consumption.

TABLE I.

Number	Time	Brake Weights	Calorimeter Temperature	Steam Pressure	Vacuum	Weight of Condensed Steam	Revolution Counter.	Load Number
0	1	2	3	4	5	6	7	Load.
1	9:32	135	229	95	20		16270	
2	:42	"	223	96	"			
3	:52	"	224.5	93	"	250		
4	10:02	"	224.2	91.5	19			I
5	:12	"	221.3	95	20			
6	:22	"	223.0	94	"	312	20743	
7	:32	340	226.0	93.[illegible]	"		21044	
8	:42	"	226.2	95	"			
9	:52	"	226	94.5	"	313.25		
10	11:02	"	223	94.4	"			II
11	:12	"	223	96	"			
12	:22	"	"	96	"	312.25	26110	
13	:32	490	226	"	"		27007	
14	:42	"	"	95.5	21			
15	:52	"	227.6	"	20	306.5		III
16	12:02	"	227	97	"	133.4		
17	:12	"	224.0	93.4	"	103.95		
18	:22	"	227	97.3	"	203.95		
19	:34	640	224.0	96.4	"		[illegible]493	
20	:44	"	222.0	93	"	242		
21	:54	"	223	96	"	245		
22	1:04	"	222	"	"	253		IV
23	:14	"	"	95	"	244		
24	:24	"	223	96	"	252	36930	

0	1	2	3	4	5	6	7	Load
25	1:34	705	212	56	70		37[illegible])	
26	:44	"	221	"	"	[illegible]		
27	:54	"	222	"	"	[illegible]		
28	2:04	"	"	"	"	[illegible]7		V
29	:14	"	"	"	"	[illegible]		
30	:24	"	220	"	"	"	[illegible]4)	
31	:34	925	"	"	"		47053)	
32	:44	"	221	"	"	335		
33	:54	"	220	"	"	[illegible]		VI
34	3:04	"	21[illegible]	"	"	373		
35	:14	"	220	"	"	[illegible]		
36	:24	"	221	"	"	375	47[illegible]00)	
37	3:5[illegible]	2100	"	64	10		47[illegible]30)	VII
38	4:0[illegible]	"	220	63	13	571	50647)	
39	:0[illegible]	1565	[illegible]	5[illegible]	"		51143)	
40	:1[illegible]	"	220	63	"	6[illegible]		
41	:2[illegible]	"	221	6[illegible]	"	6[illegible]		VIII
42	:33	"	220	60	"	6[illegible]7		
43	:43	"	21[illegible]	61	"	61[illegible]		
44	:53	"	"	"	"	615	[illegible])	

TABLE II.

O	R.P.M.	M.E.P. H.P.	M.E.P. C.P.	I.H.P. H.P.	I.H.P. C.P.	I.H.P. Total.
1	89.5	18.8	16.3	9.3	12.47	21.77
2	89	32.2	26.9	16.92	19.73	36.65
3	88	33.8	39.56	25.53	28.7	54.23
4	89	44.06	50.23	33.89	36.58	70.47
5	88	53.5	52.4	40.33	33.02	73.35
6	87	63.4	66.8	50.93	47.5	98.43
7	85	80.4	74.4	58.6	52.15	110.75
8	84	91.4	80.2	65.68	59.72	125.40

TABLE II (Continued.)

O	Corr. Scale Wts.	B.H.P.	Quality of Steam.	# of Dry Steam Per I.H.P.H.	# of Dry Steam Per B.H.P.H.
1	184.58	18.25	96.5	29.9	35.6
2	309.13	35.17	93.8	24.48	27.08
3	493.33	47.25	96.6	20.49	24.52
4	638.08	62.44	96.3	20.22	23.83
5	763.4	73.75	96.4	21.71	23.15
6	923.23	88.2	96.2	22.51	25.13
7	1148.	103.1	96.4	27.71	29.8
8	1260.90	116.4	95.6	28.25	30.45

TABLE III.

Number.	Time.	Brake Weights.	Calorimeter Temperature.	Steam Pressure.	Vacuum.	Weight of Condensed Steam.	Revolution Counter.
0	1	2	3	4	5	6	7
1	1:21	750	223	90.2	20	---	31687
2	:25	177	221	93.0	"	46.3	32040
3	:29	147	235	93.4	"	34	32404
4	:33	91	244	93	"	19.6	32765
5	:37	72	244	93.5	"	23.5	33131
6	:41	65	249	93.8	"	22	33500
7	:45	67	249.5	90	"	27	33858
8	:49	65	249.5	92.6	"	21.7	34206
9	:53	75	235	93.2	"	21	34556
10	:57	80	244	93.8	"	20.5	34950
11	2:01	173	233	92	"	21	35312
12	:05	377	227	92.4	"	57	35671
13	:09	625	226	92.8	"	37.5	36033
14	:13	720	220	91.7	"	93.5	36390
15	:17	840	221	90	"	112	36741
16	:21	905	220	87.0	19	114	37091
17	:25	827	"	87.3	20	143.5	37438
18	:29	820	"	91.5	"	137.5	37780
19	:33	720	220.5	93.5	19	123	38135
20	:37	650	222	"	20	159.7	38433
21	:41	635	224	92	"	968	38842
22	:45	630	223	89.5	"	69.5	39001

TABLE III. (Continued)

0	1	2	3	4	5	6	7
23	2:49	634	223	86.3	20	93.5	89550
24	:53	652	222	87.2	"	94.2	89904
25	:57	675	221	86	"	99	90255
26	3:01	637	222	85	"	103.6	90607
27	:05	695	221	84.3	"	103.5	90959
28	:09	"	"	86.6	19	103.1	91310
29	:14	710	220	85	20	103	91750
30	:17	693	"	83.5	"	94.2	92016
31	:21	700	220.2	82.6	"	93.5	92365
32	:25	703	220	83.2	"	106	92714
33	:29	650	221	82	"	112	93066
34	:33	700	222	82.5	"	101.8	93418
35	:37	910	220	83.2	"	109	93768
36	:41	1000	219.5	80.4	19	135.2	94119
37	:45	933	213	82.6	17	176.5	94462
38	:49	727	222	81.5	19	149.5	94802
39	:53	680	223	83.5	21	113.5	95143
40	:57	630	224	89.	20	88.5	95501
41	4:01	657	"	91.5	"	85	95857
42	:05	572	224.2	92	19	92	96210
43	:09	495	223.5	92.8	20	87.5	96566
44	:13.5	490	220	93.6	"	74.1	96964
45	:17	"	223	94	22	53.5	97278
46	:21	450	"	94.4	21	63.2	97634
47	:25	425	2 0.3	"	"	66	97991
48	:32	343	232	94	"	101	98017

TABLE IV.

		M.E.P.		I.H.P.		I.H.P.
O	R.P.M.	H.E.	C.E.	H.E.	C.E.	Total.
1	——	20.8	19.4	——	——	——
2	93	16.4	15.4	12.37	11.6	23.97
3	91	6.4	9.4	5.18	7.04	12.22
4	90	5.4	11.4	4.28	8.43	12.71
5	92	-3.0	-2.0	-2.26	-1.59	——
6	"	"	"	-0.36	"	——
7	90	1.4	2.4	1.21	1.77	2.98
8	92	3.4	5.4	2.93	4.01	7.01
9	"	1.4	3.4	1.35	2.56	3.91
10	89	"	3.9	1.13	2.84	3.97
11	90	-3.	-3.	-2.3	-2.23	——
12	"	6.9	9.9	5.45	7.33	12.78
13	"	23.4	23.4	18.17	17.35	35.52
14	89	40.4	39.9	30.84	29.37	60.21
15	88	51.4	46.9	39.77	33.99	73.76
16	88	61.9	58.4	46.66	42.35	89.02
17	87	62.4	56.4	46.46	40.47	86.93
18	"	——	——	——	——	——
19	"	60.4	56.4	44.96	40.47	85.40
20	89	54.4	52.4	41.54	38.46	80.00
21	88	48.4	45.4	36.59	32.91	69.5
22	90	44.4	42.9	34.40	31.84	66.24
23	87	43.4	40.9	32.36	29.33	61.69
24	88	41.4	38.9	31.21	28.19	59.40
25	"	43.5	40.4	32.71	29.29	62.00
26	"	44.9	41.4	33.37	30.01	63.38
27	"	43.4	"	33.71	30.01	63.72
28	"	46.9	43.4	35.39	31.47	66.86

TABLE IV. (Continued.)

O	R.P.M.	M.E.P. H.E.	M.E.P. C.E.	I.H.P. H.E.	I.H.P. C.E.	I.H.P. Total.
29	88	47.42	43.4	35.74	31.47	67.21
30	89	46.92	"	35.76	31.85	67.61
31	87	48.42	45.4	36.11	32.57	68.67
32	"	45.4	41.4	33.93	29.70	63.63
33	88	43.4	40.4	32.71	29.29	62.00
34	"	47.9	43.4	36.11	31.37	67.48
35	"	46.4	44.4	34.99	32.19	67.18
36	"	51.9	48.9	39.14	35.48	74.62
37	86	61.4	48.9	45.26	35.43	80.69
38	85	74.4	72.9	54.13	51.09	105.27
39	87	63.4	61.4	47.27	44.06	91.34
40	88	48.4	47.4	36.49	34.38	70.87
41	"	39.4	38.4	29.69	29.04	58.73
42	89	41.4	40.4	31.56	29.66	61.22
43	"	43.4	41.4	33.09	30.37	63.46
44	88	34.4	34.4	25.84	24.94	50.78
45	90	33.4	32.4	25.73	24.04	49.82
46	89	30.4	32.4	23.19	23.77	46.96
47	"	31.4	31.4	23.96	23.03	46.99
48	"	26.4	28.4	20.15	19.84	39.99
49	"	21.4	24.4	16.32	16.89	33.21

TABLE IV. (Continued.)

0	Corr. Scale Wts.	B.H.P.	Quality of Steam.	# of Dry Steam Per I.H.P.H.	# of Dry Steam Per B.H.P.H.
1	294.2	----	96.8	-----	-----
2	241.3	23.3	97.	30.24	30.6
3	117.4	11.4	97.25	40.51	43.47
4	56.00	5.5	97.6	22.59	52.2
5	37.0	3.7	97.85	-----	113.0
6	30.0	3.0	98.0	-----	107.8
7	45.0	4.5	97.9	-----	88.15
8	54.0	5.5	"	45.5	57.95
9	50.0	5.0	97.25	78.2	61.2
10	40.0	3.9	97.65	75.6	77.1
11	45.0	4.5	97.3	-----	68.19
12	137.6	13.6	96.75	64.9	60.8
13	341.1	33.7	96.7	35.7	37.65
14	588.6	57.5	96.4	23.2	24.0
15	689.5	66.6	96.5	22.0	24.33
16	803.3	77.6	"	17.55	21.37
17	868.3	83.0	"	22.4	23.46
18	850.3	81.3	96.4	-----	24.48
19	783.4	74.8	96.3	21.7	24.7
20	783.5	70.0	96.4	28.85	24.7
21	613.6	59.2	96.6	20.4	24.
22	598.6	"	"	19.55	21.9
23	593.6	56.7	96.7	20.8	22.64
24	597.8	57.7	96.6	23.0	23.65
25	615.6	59.4	"	23.1	24.13
26	638.6	61.7	"	23.55	24.32

TABLE IV (Continued.)

O	Corr. Scale Wts.	B.H.P.	Quality of Steam	# of Dry Steam Per I.H.P.H.	# of Dry Steam Per B.H.P.H.
27	650.6	62.8	96.6	[illegible]	23.89
28	649.6	"	96.55	[illegible]	23.79
29	649.6	"	"	22.05	23.02
30	673.5	65.8	"	24.05	24.71
31	657.6	62.8	96.65	20.75	22.33
32	663.6	63.4	"	24.15	34.23
33	666.6	64.4	96.5	26.11	25.13
34	653.6	63.2	"	21.95	23.32
35	725.4	70.1	96.45	23.5	23.51
36	373.2	34.4	"	26.21	23.17
37	1043.1	93.5	96.5	30.65	29.3
38	901.2	34.1	96.7	20.6	42.98
39	690.5	66.	96.75	30.81	26.06
40	583.6	56.43	96.7	18.1	22.72
41	593.6	57.4	96.6	20.93	21.45
42	620.6	60.7	"	21.77	21.96
43	535.3	52.4	96.8	20.25	24.52
44	458.9	54.4	96.35	19.25	24.23
45	443.9	43.9	96.75	19.47	19.35
46	"	43.4	96.7	27.06	22.79
47	413.9	40.4	96.3	20.4	24.51
48	489.1	47.8	96.9	22.94	20.06
49	312.2	30.5	"	-----	43.15

TABLE V.

Number.	Time.	Brake Weights.	Calorimeter Temperature	Steam Pressure.	Vacuum.	Weight of Condensed Steam.	Revolution Counter.	Barometer Readings.
0	1	2	3	4	5	6	7	
1	1:15	390	231	90	20		2710	29.46
2	1:19	345	"	"	"	55.0	3064	
3	1:23	320	"	90.5	"	49.5	3424	
4	1:27	295	230	"	"	"	3785	
5	1:31	"	228	91	"	53.5	4139	
6	1:35	"	"	"	"	"	4492	
7	1:39	"	229	90.5	"	51.5	4854	
8	1:43	"	"	"	"	52.5	5213	
9	1:47	"	228	90	21	53	5580	
10	1:51	"	230	"	"	49.5	5940	
11	1:55	335	227	"	"	59.5	6292	
12	1:59	370	228	"	20	62.5	6658	
13	2:03	425	226	"	"	63.5	7020	
14	2:07	615	224	"	"	91	7372	
15	2:11	650	223	89	"	100.	7730	
16	2:15	660	222	"	"	95	8081	
17	2:19	"	223	"	"	91.5	8432	
18	2:23	650	224	"	"	92.5	8775	
19	2:27	660	222	90	"	96	9130	
20	2:31	"	"	91	"	97.5	9484	
21	2:35	"	223	"	"	96.5	9823	
22	2:39	665	222	90	"	100.5	10186	
23	2:43	660	223	"	"	103.	10541	

TABLE V. (Continued.)

0	1	2	3	4	5	6	7
24	2:47	650	223	90	20	98	10896
25	2:51	480	225	"	"	84.5	11246
26	2:55	650	224	"	"	37.5	11604
27	2:59	720	"	"	"	102.5	11960
28	3:03	750	223	"	"	.110.5	12313
29	3:07	800	222	89	"	114.5	12653
30	3:11	825	220	"	"	124.	11310
31	3:15	860	221	"	"	178.	[illegible]
32	3:19	920	"	[illegible]	"	135.	13704
33	3:23	1005	219	88	18	152.	14056
34	3:27	1160	218	87.5	17	197.5	14398
35	3:31	1230	219	85	"	323.5	14730
36	3:35	1130	222	"	13	133.0	14061
37	3:39	1075	"	"	"	214.5	15414
38	3:43	1000	"	86	19	180.5	15759
39	3:47	950	"	88	20	146.5	16104
40	3:51	935	"	89	"	143.5	16456
41	3:55	840	"	90	21	126.5	16799
42	3:59	800	"	"	20	114.5	17161
43	4:03	775	223	"	"	111.5	17509
44	4:07	660	224	"	21	99.5	17362
45	4:11	590	226	"	"	86	18218
46	4:15	570	"	"	"	85	18569
47	4:19	470	228	"	"	75	18935
48	4:23	440	230	"	20	65	19281
49	4:27	390	"	"	"	52	19636

TABLE VI.

		M.E.P.		I.H.P.		I.H.P.
O	R.P.M.	H.E.	C.E.	H.E.	C.E.	Total.
1	-----	24.4	23.9	---	---	-----
2	90.	22.4	21.4	17.06	15.71	32.77
3	90.	20.4	20.4	15.73	15.15	30.88
4	90.	16.4	18.4	12.65	13.66	26.31
5	89..	17.4	"	13.29	13.51	26.80
6	"	"	19.4	"	14.25	27.54
7	90	"	17.9	13.42	13.29	26.71
8	"	"	18.4	14.20	13.66	27.86
9	92	19.4	19.4	15.29	14.62	29.91
10	90	17.9	"	13.80	14.40	28.20
11	88	18.4	20.4	13.87	14.81	28.68
12	92	23.4	22.9	18.45	17.38	35.83
13	91	27.4	24.4	21.36	18.32	39.68
14	88	37.9	36.9	28.59	26.79	55.38
15	90	46.4	42.9	35.79	31.85	67.64
16	88	"	"	34.99	31.15	66.14
17	"	44.4	42.4	33.49	30.79	64.28
18	85	43.4	40.4	31.60	28.32	59.92
19	89	"	41.9	33.12	30.75	63.87
20	"	34.9	42.4	33.50	31.12	64.62
21	85	45.9	41.9	33.41	29.39	62.80
22	91	46.4	42.4	36.15	31.83	67.98
23	89	42.4	43.4	32.38	31.88	63.26
24	"	43.9	43.9	33.50	32.23	65.73
25	83	38.4	37.9	28.95	27.51	56.46
26	90	40.4	40.4	31.15	30.00	61.15
27	89	46.9	46.4	35.30	34.09	69.39

TABLE VI (Continued)

O	R.P.M.	M.E.P. H.E.	M.E.P. C.E.	I.H.P. H.E.	I.H.P. C.E.	I.H.P. Total.
28	83	49.9	49.4	37.60	35.83	73.43
29	86	53.9	53.4	39.70	37.89	77.59
30	90	55.4	54.4	42.71	40.40	83.11
31	87	56.9	56.4	42.40	40.50	82.90
32	85	60.4	59.4	43.99	41.65	85.64
33	88	64.9	64.9	48.91	47.10	96.01
34	86	73.4	76.4	57.75	54.20	111.95
35	"	85.4	84.4	60.90	59.85	120.75
36	"	85.9	67.4	63.30	47.80	111.10
37	83	84.9	67.4	64.00	45.30	109.30
38	86	71.4	67.4	55.60	47.80	103.40
39	"	67.4	63.4	49.65	44.95	94.60
40	83	66.4	"	50.05	46.00	96.05
41	86	57.9	55.9	42.65	39.65	82.30
42	91	44.9	57.4	35.00	40.10	75.10
43	87	53.4	50.4	39.30	36.70	76.00
44	83	45.4	44.4	34.21	32.21	66.42
45	83	40.4	40.4	30.82	29.68	60.50
46	83	35.9	35.4	27.03	25.70	52.73
47	83	31.9	31.9	24.35	23.32	47.77
48	"	29.4	29.4	22.43	21.59	44.02
49	"	26.4	27.4	20.52	20.12	40.64

TABLE VI. (Continued.)

0	Corr. Scale Wts.	B.H.P.	Quality of Steam.	# of Dry Steam Per I.H.P.H.	# of Dry Steam Per B.H.P.H.
1	------	------	97.1	-----	-----
2	309.	30.21	"	24.47	25.63
3	334.22	33.11	96.9	23.30	24.60
4	259.27	25.62	"	27.35	29.22
5	"	25.35	96.3	28.50	30.62
6	"	"	"	28.10	"
7	"	25.62	96.25	28.90	30.20
8	"	"	"	27.40	28.75
9	"	26.21	"	25.74	26.37
10	"	25.62	96.9	25.60	28.03
11	259.19	23.90	96.3	21.50	29.90
12	334.12	33.77	"	35.30	26.39
13	339.02	33.35	96.7	22.22	27.72
14	573.63	55.90	96.6	23.63	27.59
15	633.53	60.60	"	21.45	23.90
16	623.61	60.20	96.55	20.75	22.24
17	"	"	96.6	20.62	22.02
18	613.63	57.20	"	22.32	23.43
19	623.61	60.90	96.55	21.72	22.22
20	"	"	96.5	21.32	23.13
21	"	53.15	"	22.22	24.22
22	678.61	62.72	"	21.40	23.17
23	623.61	60.90	96.55	23.60	24.49
24	613.63	60.16	"	21.61	23.60
25	443.87	42.85	96.7	21.73	23.30
26	613.63	60.60	96.6	20.75	20.91

TABLE VI. (Continued.)

O	Corr. Scale Wts.	B.H.P.	Quality of Steam.	# of Dry Steam Per I.H.P.H.	# of Dry Steam Per B.H.P.H.
27	633.30	66.33	96.6	21.90	22.88
28	713.43	62.62	[illegible].55	21.20	24.23
29	7[illegible].40	7[illegible].10	"	21.40	27.01
30	733.37	77.20	96.45	21.60	27.04
31	823.33	87.80	96.5	22.37	27.53
32	833.25	87.40	"	22.00	27.71
33	903.13	93.50	96.4	21.96	27.51
34	1122.90	100.00	96.3	25.50	30.90
35	1100.13	112.60	96.5	30.90	40.55
36	1077.01	103.20	96.65	23.00	[illegible].00
37	1033.13	100.20	"	23.40	30.00
38	963.15	90.90	96.6	26.05	29.70
39	917.21	96.20	96.55	22.40	[illegible].01
40	897.25	90.80	"	21.60	27.04
41	805.31	71.80	96.5	22.93	33.07
42	763.40	76.20	"	22.03	22.72
43	733.43	70.50	96.55	21.34	29.02
44	623.62	60.20	96.6	21.70	23.95
45	553.72	54.10	96.7	20.91	27.06
46	433.00	43.70	"	23.30	26.40
47	473.94	42.40	96.3	21.29	25.00
48	404.00	39.47	96.9	21.45	25.92
49	354.09	34.00	"	19.60	21.06

TABLE VII.

CALIBRATION OF INDICATORS.

Head End.

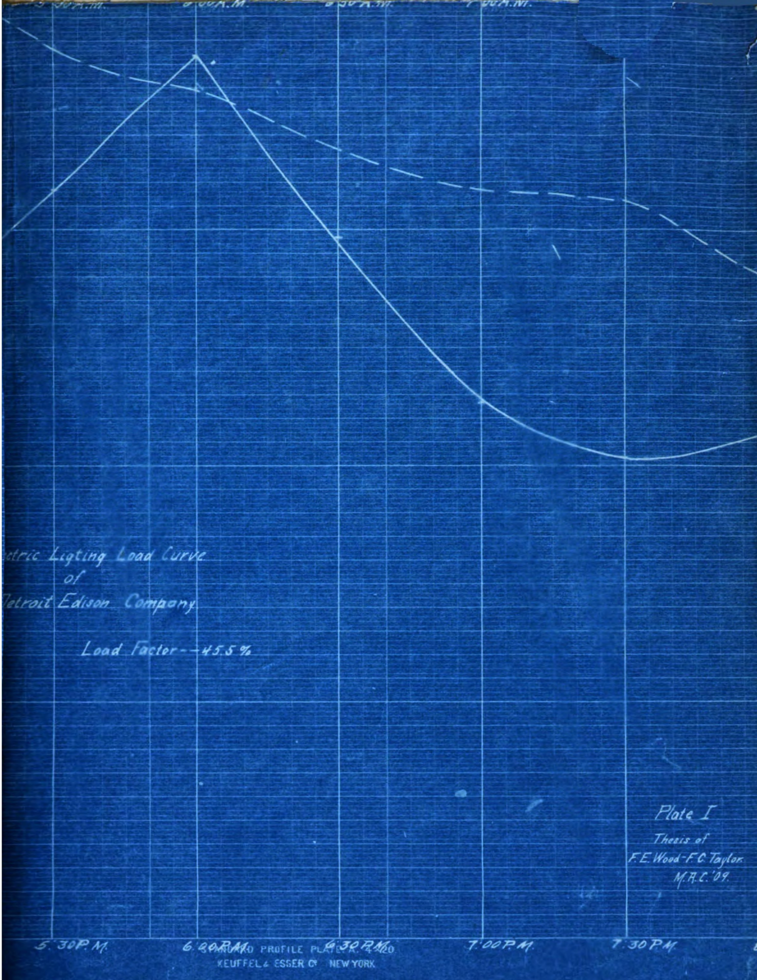
Pounds Actual Press.	Av. Press. from Card. Up.	Av. Press. from Card. Down.	Error. Up.	Error. Down.	Av. Press. from Card. Up.	Av. Press. from Card. Down.	Error. Up.	Error. Down.
10	10.5	9.5	+ 0.5	-0.5	9.5	11	-0.5	+1
20	20.	20.	0	0	20.	22	0	+ 2
30	31.5	32.	+1.5	+2.	31.	33.5	+ 1	+ 3.5
40	41.	42.5	+ 1.	+2.5	42.	44.	+ 2	+ 4.
50	53.	54.	+ 3.	+ 4.	53.5	55.5	+3.5	+5.5
60	63.	65.	+ 3.	+5.	64.5	66.	+ 4.5	+6.
70	75.	77.	+ 5.	+ 7.	76.5	77.	+6.5	+7.
80	85.	86.	+ 5.	+ 6.	87.	87.	+7.	+7.
90	95.	995.	+ 5.	+ 5.	97.	97.	+ 7.	+7.
			24.	31.			31.	43.

$$\text{Average} = \frac{(24+31+31+43)}{9 \times 4} = 3.58\%\ +\text{error on H.E.}$$

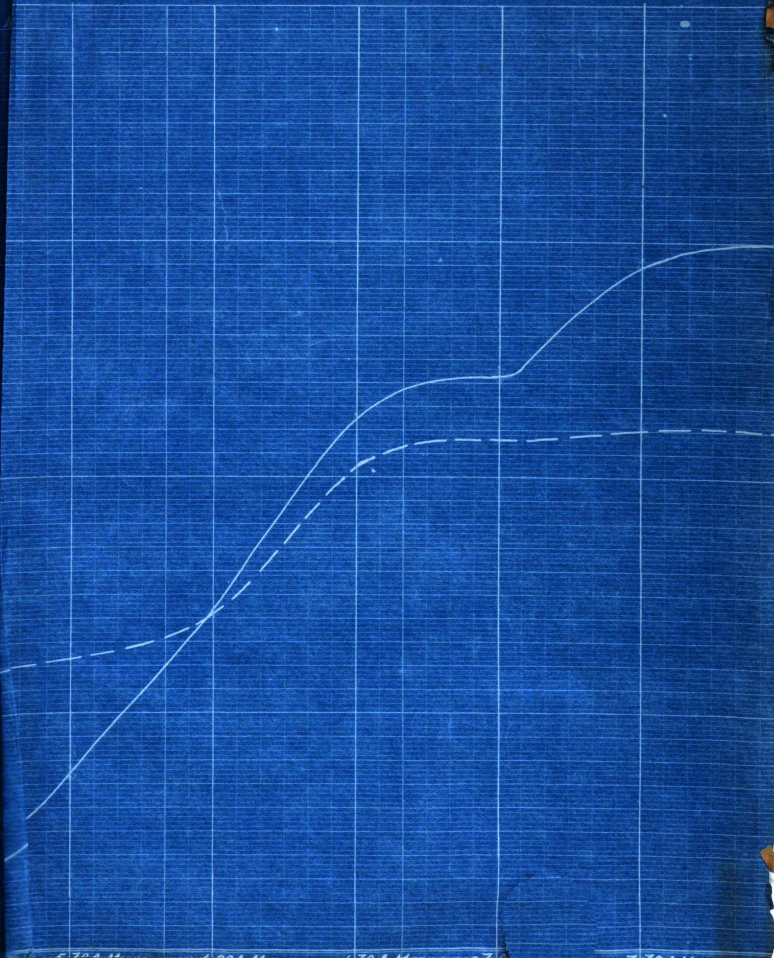
Crank End.

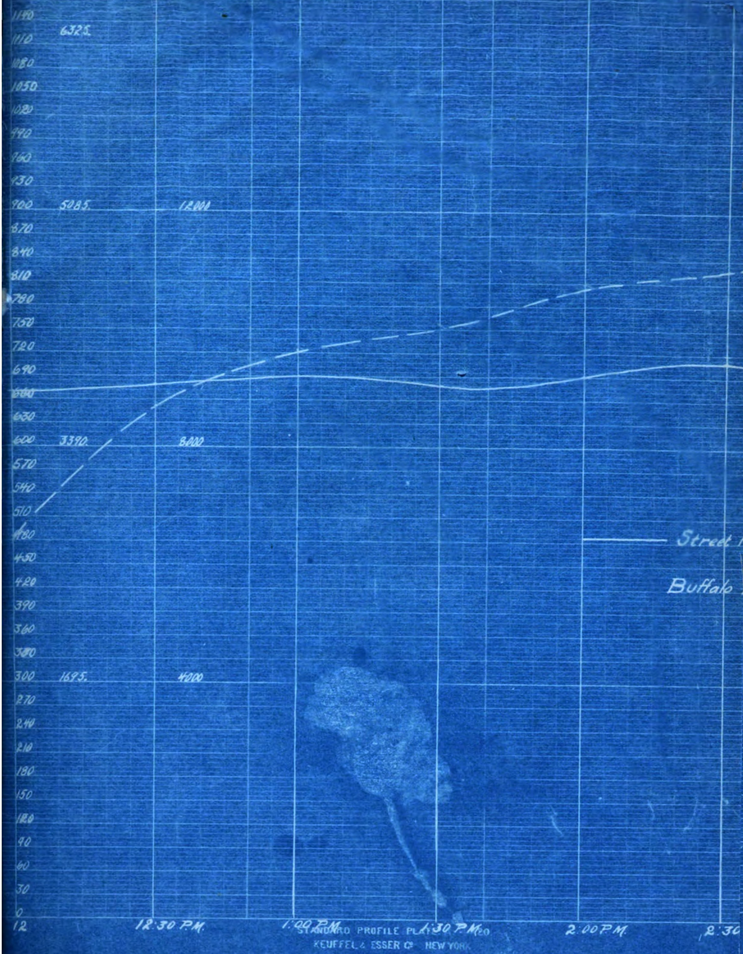
Pounds Actual Press.	Av. Press. from Card. Up.	Av. Press. from Card. Down.	Error. Up.	Error. Down.	Av. Press. from Card. Up.	Av. Press. from Card. Down.	Error. Up.	Error. Down.
10	11	12	+ 1	+ 2	10.5	11	+.5	+ 1
20	21	22.5	+ 1	+ 2.5	21.5	22.5	+1.5	+ 2.5
30	31	33	+ 1	+ 3	31.5	33	+1.5	+ 3.
40	41	43.5	+ 1	+ 3.5	[illegible]	43.5	+ [illegible]	+ 3.5
50	51	53.5	+ 1	+ 3.5	51.5	54.5	+ 1.5	+ 4.5
60	61	63	+ 1	+ 3	[illegible]	65.5	+ [illegible]	+ 5.5
70	72	74	+ 2	+ 4	73.5	75	+ 3.5	+ 5
80	82	84	+ 2	+ 4	[illegible]	87	+ 2	+ 7
90	93	93.5	+ 3	+ 3.5	[illegible]	93	+ 3	+ 3
			13.	29.			18.	35.

$$\text{Average} = \frac{(13+18+29+35)}{9 \times 4} = 2.63+\ \text{Error on C.E.}$$

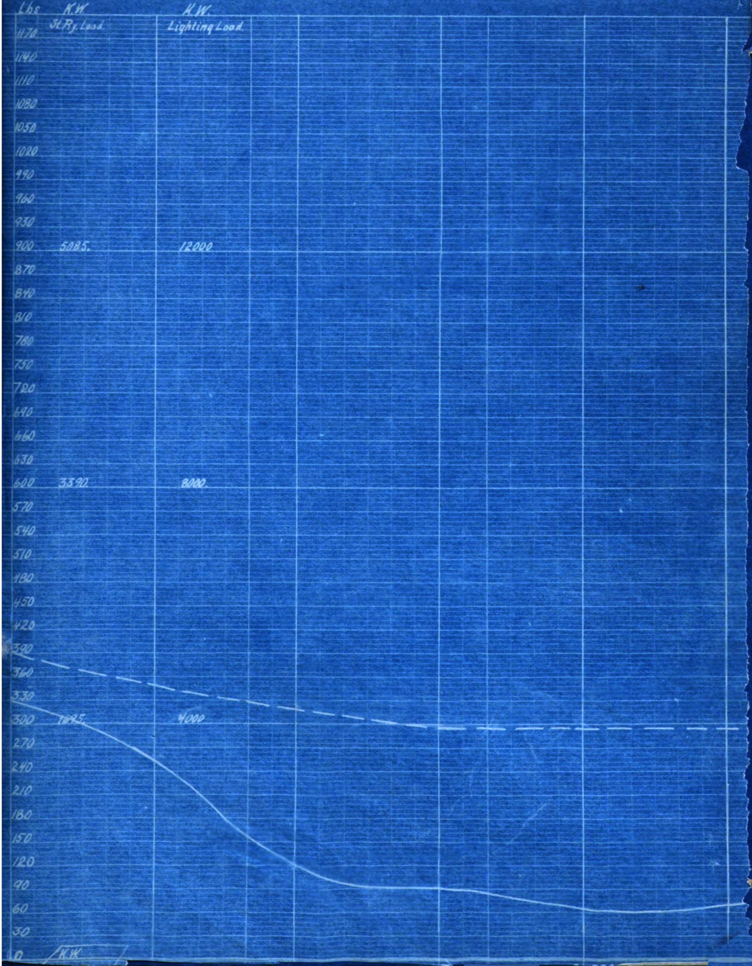


5:30P.M.
6:00P.M.
6:30P.M.
7:00P.M.
7:30P.M.
STANDARD PROFILE PLATE. A. 4420
KEUFFEL & ESSER Co NEW YORK
ctric Ligting Load Curve
of
Detroit Edison Company
Load Factor--45.5%
Plate I
Thesis of
F.E.Wood-F.C.Taylor
M.A.C.'09.





1140
1110
1080
1050
1020
990
960
930
900
870
840
810
780
750
720
690
660
630
600
570
540
510
480
450
420
390
360
330
300
270
240
210
180
150
120
90
60
30
0
6325.
5085.
12000
3390.
8000
1695.
4000
Street
Buffalo
12
12:30 P.M.
1:00 P.M.
1:30 P.M.
2:00 P.M.
2:30
STANDARD PROFILE PLATE No 20
KEUFFEL & ESSER Co NEW YORK


Lbs
K.W
St.Ry. Load
K.W.
Lighting Load
1170
1140
1110
1080
1050
1020
990
960
930
900
5085.
12000
870
840
810
780
750
720
690
660
630
600
3390.
8000.
570
540
510
480
450
420
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180
150
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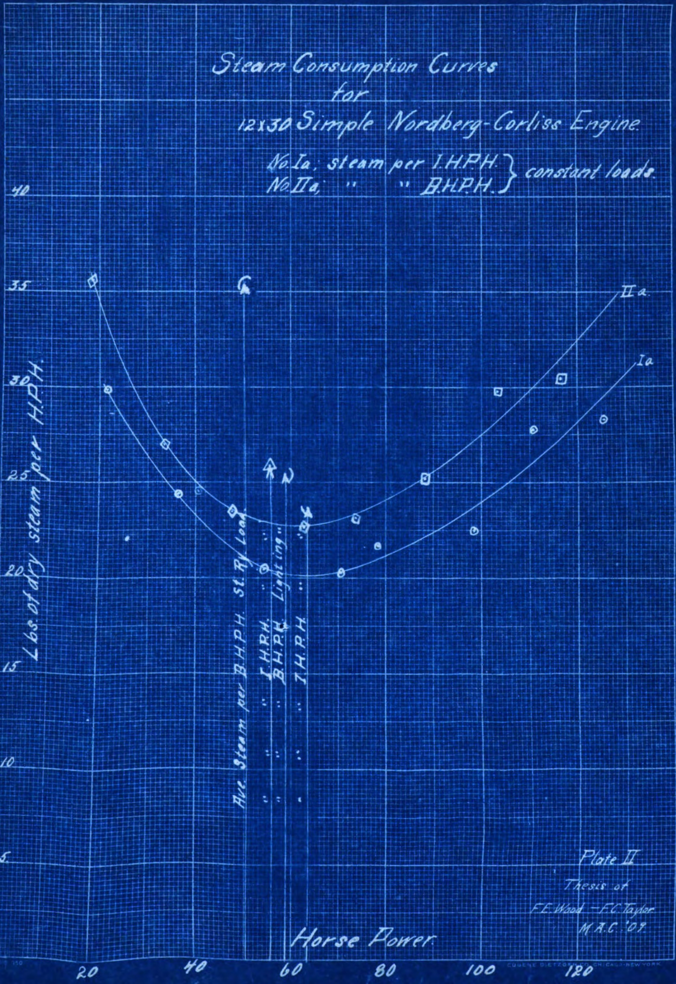
60
30
0
K.W



Steam Consumption Curves
for
12x30 Simple Nordberg-Corliss Engine.
No. Ia, steam per I.H.P.H.
No. IIa, " " B.H.P.H.
constant loads.
Lbs. of dry steam per H.P.H.
Horse Power
Ave. Steam per B.H.P.H. St. Ry. Load
" " I.H.P.H. "
" " B.H.P.H. Lighting
" " I.H.P.H. "
IIa
Ia
5
10
15
20
25
30
35
40
20
40
60
80
100
120
Plate II
Thesis of
F.E. Wood - F.C. Taylor
M.A.C. '09.

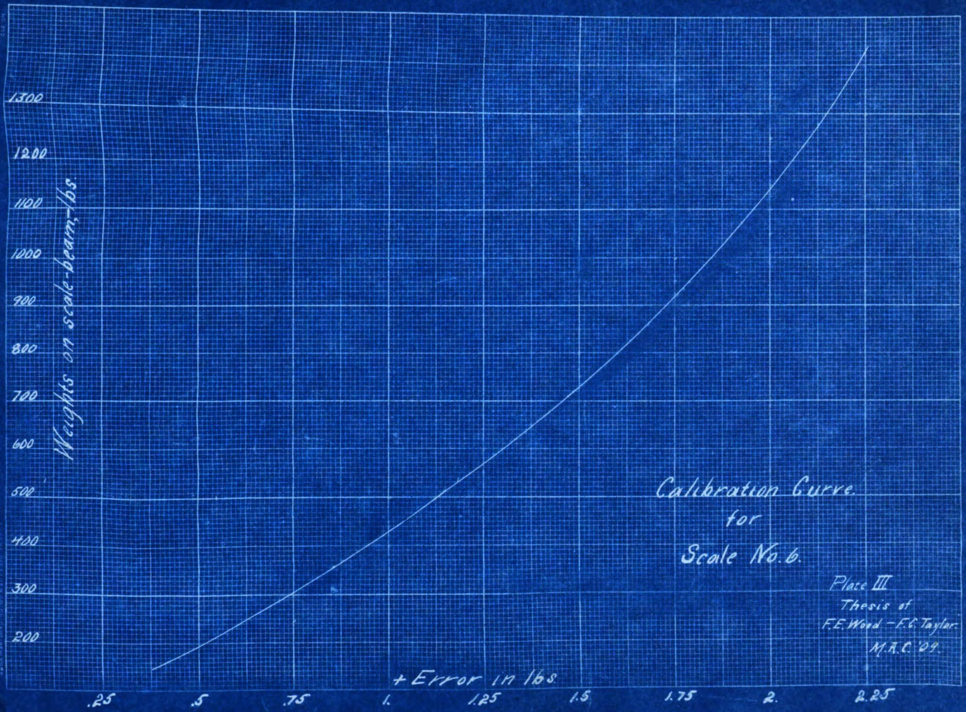

Calibration Curve
for
Scale No. 6.
Plate III
Thesis of
F.E. Wood - F.C. Taylor.
M.A.C. '09.
Weights on scale-beam, lbs.
1300
1200
1100
1000
900
800
700
600
500
400
300
200
+ Error in lbs.
.25
.5
.75
1.
1.25
1.5
1.75
2.
2.25

Fig. 1c.

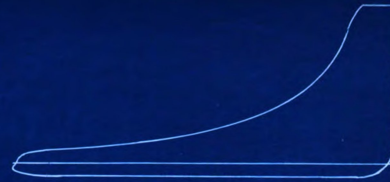


Fig. 2c.

Fig. 1b.

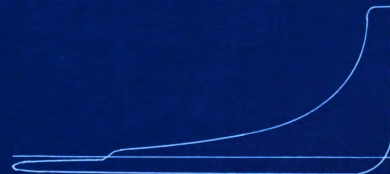


Fig. 2b.

Fig. 1a.

Fig. 2a.

Thesis
of
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M.A.C. '09.

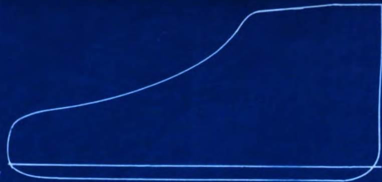

Fig. 1f.

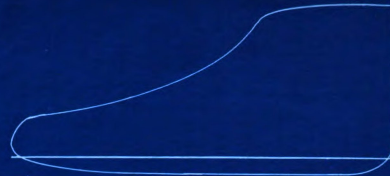

Fig. 2f.

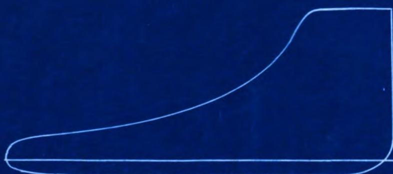

Fig. 1e.

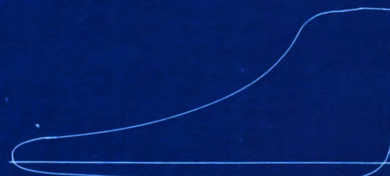

Fig. 2e.

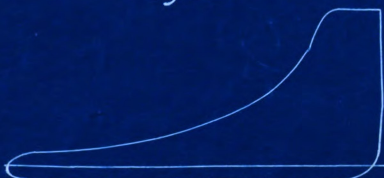

Fig. 1d.

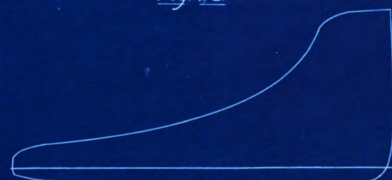

Fig. 2d.

Thesis
of
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M.A.C. '09.

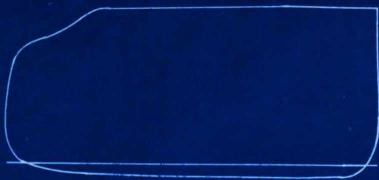

Fig. 1h.

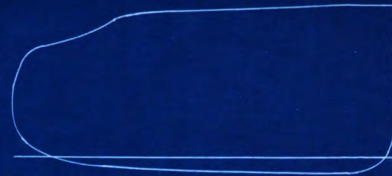

Fig. 2h.

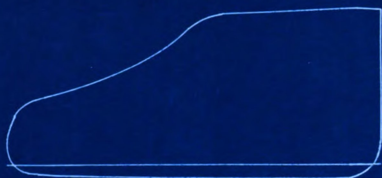

Fig. 1g.

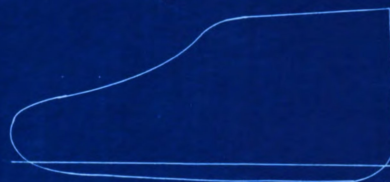

Fig. 2g.

Thesis

Fig. 3a.

Fig. 4a.

Fig. 3b.

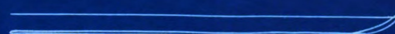

Fig. 4b.

Fig. 3c.

Fig. 4c.

Thesis

Fig. 5a

Fig. 6a.

Fig. 5b.

Fig. 6b.

Fig. 7.

Fig. 8.

Thesis
of
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