THESIS

Comparing I8 Horse Power Gasoline Engine

with

7" by I0" Condensing Steam Engine

by

J.F.Poole and L.O.Gordon

I906.

This thesis was contributed by

Mr. L. O. Gordon

under the date indicated by the department stamp, to replace the original which was destroyed in the fire of March 6, 1916.

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10-4-51
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Purpose

The question often arises at the present time as to whether a steam or a gasoline engine will be the more economical power developer. Accordingly this thesis has been run to give some idea of the relative economy of small units.

The gasoline engine used was a four cycle Old's Gasoline Engine, with an eight and a half inch cylinder by fourteen inch stroke. It is governed by a hit and miss governor, and is rated at eighteen horsepower. The engine was moved from the "Olds Works" in Lansing to the M.A.C. laboratory, where the test was run, and most of the apparatus used was designed and and built by the writers. The methods used were those employed by the M.A.C. Experimental Laboratory, with some additional ideas gained by numerous visits to the testing rooms of the "Olds People."

The object of this test was to determine the brake horsepower, thermal and mechanical efficiency, cost per horse-power per hour and to compare with similar results obtained for the steam engine.

The apparatus used in the test was as follows. One Olds Gasoline Engine, one Prony brake, one set of small platform scales graduated to hundredths of a pound, one set of large scales upon which the barrel for collecting cooling water might be weighed. One barrel, a gasoline tank, two thermometers, a speed indicator, a battery of five cells, an explosion counter, American Thompson Indicator and a few wrenches.

After all the apparatus had been connected as shown in (Plate I) the engine was started up and as it was a new machine, and had just been taken from the testing floor of the makers. it was not thought advisable to change any of the adjustments. Besides this test was to be a comparative one and hence both engines should be run as they came from the factory.

The duration of each test was twenty minutes and the loads varied from zero to a maximum by two horse power increments. In taking each test the engine was allowed to run until working at constant conditions before taking any readings. Readings of each type were taken every five minutes and recorded upon an auxiliary log sheet. An average of the five readings thus taken was placed upon the final log sheet(Plates 7-8). In this way if any single reading was taken erroneously, it was readily discovered by an inspection of the log sheet. In order to check the possibility of any temporary freak working of the engine, four separate trials were run for each load. In the final data sheet (Plate II) appears results obtained by averaging the results of all tests of like load;(Plates 8-I0) and hence it is seen that each result shown upon this sheet is supported by twenty separate readings and we unhesitatingly submit their results as good evidence of the normal working of the engine.

The brake horse power was obtained by noting the speed of the engine and the load it was carrying during each test. A set of small platform scales registered the load being carried and a speed counter applied to the end of the shaft, the speed. From this data the horse power is found by aid of the formula for brake horse power shown upon formula plate.

The load was measured by placing a set of scales under the brake arm. The brake was an ordinary Prony brake and was applied to a special friction pulley, which was bolted to one of the fly-wheels of the engine. The brake was lubricated by placing slices of salt pork between the rubbing surfaces. A detailed sketch of the brake and cooling device appears on Plate [illegible].

The indicated horse power was computed from the indicator cards and the number of explosions. The cards were taken with an American Thompson indicator, using a one hundred and twenty pound spring with a small piston, thus giving ordinates two hundred and forty pounds to the inch. The number of explosions was counted by the device shown in Plate [illegible]. Plate [illegible] shows a detail of the manner of connecting the indicator, reducing motion etc. The computing was by use of formula for indicated horse power, shown on Plate [illegible] of formulae.

The amount of gasoline used was noted by weighing the supply tank before and after the test. The scales used being graduated to hundredths of a pound. The heat lost to the cooling jacket was found by taking the temperature of the water before and after it passed the jacket and by catching and weighing it as it came out. Formula shown upon (Plate 6 [illegible]) will explain computations.

The method of counting the explosions is readily seen in the sketch, the valve leading to the cylinder of the counter was for the purpose of muffling down the force of the explosion. A battery of five cells, in series, furnished the spark for the igniter. No muffler was used, both exhausts passing out into the open air separately. Owing to fluctuations in the water pressure great trouble was had to keep a constant amount passing through the jacket.

In order to know how much heat was being furnished to the engine, samplesof the gasoline were tested in the Chemical Laboratory and found to be sixty nine degrees Beaumé test and from data on record there, the thermal equivalent of gasoline at this test is twenty thousand British Thermal Units per pound, and there are five and eighty six hundredths pounds in one gallon. Assuming gasoline to cost fourteen cents per gallon, we get by multipling the gasoline per horse power per hour by fourteen cents, the cost per horse power per hour.

The Steam Engine Test.

The engine used for this test was a simple single cylinder, plain slide valve, fly wheel governor, surface condensing, engine having a cylinder seven inches in diameter and a ten inch stroke. It was built by the Lansing Iron Works of Lansing, Mich., and, at the time this test was made, had been in continuous service in the Mechanical Laboratory for fifteen years and was in a very poor condition for making a satisfactory test. The piston rings were so badly worn that the steam passed through between them and the cylinder walls quite as though there were no rings present at all, and the stuffing boxes were also in a very unsatisfactory condition. We however used this particular engine for our test because our time was too limited to permit of our going away from the college grounds to make the test.

The engine was supplied with a forty two inch fly-wheel having a nine inch face. As there were no convenient means for fastening a small brake pulley on either the crank shaft or the fly-wheel arms, and since the heating due to the friction of an ordinary form of Prony brake, on a fly-wheel of such size is enormous, we decided to make two separate tests on the engine as follows;-

I. To determine the "Mechanical Efficiency."

2. To determine the "Thermal Efficiency," "Steam Consumption" and the cost of running per Brake Horse Power per hour.

These two tests making a very complete and in our particular case a very easy and efficient method for making a complete test on the engine.

For taking indicator cards we used a [illegible] indicator No. I3I7 with a forty pound spring. The same reducing motion [illegible] (Plate II) was also used in both tests.

Before making either test we took a couple of cards while the engine was running light to see if the valves were properly set for an economical steam distribution. This card showed us that the head end was doing all the work and that the crank end was doing negative work. We then changed the valve setting to get as near an equal distribution as possible at each end. A glance at the cards on Plates II-IV and IV will show how well we succeeded in our efforts.

Test No. I.

For our use in making this test we built a rope brake having eight strands of three-fourths inch rope for a friction surface. The set up for this test is shown on Plate IV. The tension in the rope was varied by means of the hand-wheel "A" which served as a very convenient and efficient method of changing the load on the engine.

The end of the brake arm was allowed to come to rest on the scale pan of a pair of Buffalo scales. The weights on the scale beam were varied by five pound increments and at each separate increment the tension in the rope was increased until the weight at the end of the brake arm just balanced that on the scale beam. While in this position an indicator card was taken simultaneously with the speed of the engine. Three such cards were taken for each increment of load. The average I.H.P. and B.H.P. computed from these three readings was recorded on the log sheet (Plate [illegible]).

The formulae for the computations in both tests are recorded on Plates [illegible]-19 and need no comment here.

The curves on Plate [illegible] were obtained by plotting "B.H.P." as ordinates and "I.H.P." and "Mechanical Efficiency" as abscissae. The friction curve shows that the engine friction is practically a constant quantity and we have so considered it in computing the "Mechanical Efficiencies" on Test 2. We do not feel any hesitancy in assuming this since it agrees with what other experimenters have found before, that is, that in small engines the friction is a constant quantity.

Test No. 2.

The general set up for this test is shown on Plate [illegible]. In this test it was necessary that we have a constant load throughout each separate load increment and yet one that could be very easily varied to suit the conditions of each separate load increment.

For our purposes we belted the engine to a ten K.W. generator which was in the engine room. The load was obtained by connecting a water ~~reostat~~ rheostat and a series of light banks in parallel with the line wires and this served as a very efficient and easy way of varying the load. The water rheostat was constructed as follows;- We filled an ordinary oil barrel with a solution of salt and water. The two line terminals were connected to two large flat iron plates, one of which was placed in the solution and allowed to rest on the bottom of the barrel.

The other was also immersed in the solution but was fastened so as to be easily raised or lowered, as we desired to change its position with respect to the other plate. Since the resistance of the solution was not very great, we had a very ready means for drawing a heavy current from the machine and thus of increasing the load on the engine. The light banks were put into the line to serve as an easy means for keeping the load constant throughout each separate test. The passing of the current through the solution in the barrel tended to decompose it and reduce the resistance and cause to let more current flow. While this action was not very great, yet it was X enough to affect our results quite appreciably. To neutralize this effect and thus we secured a constant load throughout the whole test.

We could not get the full rated power from the generator because due to our particular set up, the speed than that at which the load was rated, so that when we were drawing 25% overload current, the engine only developed [illegible] I.H.P. While running at this load the generator heated up so that it didn't deem it advisable to draw any more current for fear of burning up the machine.

Each separate test was of twenty minutes duration. The quality of steam was determined by means of a [illegible] Throttling Calorimeter. See (Plate [illegible]) for data.

Readings of the "Pressure in the Calorimeter Chamber", "Pressure on the Steam Main", of the "Barometer", the "Temperature in the Calorimeter Chamber", the "Speed of the Engine", were taken and recorded on an auxiliary log sheet and the average of these five readings recorded on the log sheet (Plate [illegible]).

The thermometer used in this test was calibrated as follows;- Steam was allowed to pass through a pipe in which its pressure and temperature could be read. The pressure was measured by a method known as "dead weights" and the temperature measured, with the thermometer being tested. The difference between this reading and that taken from the steam tables corresponding to the same pressure is the error. In this case the thermometer read → [illegible]° degrees too low.

The steam gauge was standardized by comparing it with a Crosby Standard Gauge and was found to read four pounds too high at the pressure used during the test. This pressure was corrected for this error and barometric pressure and recorded on the data sheet (Plate [illegible]).

The condensed steam was run into a barrel balanced on a pair of Buffalo scales and weighed at the end of each test ed from this the Steam Consumption was computed.

The formulae for all the computations on Plates [illegible] are recorded on Plates [illegible].

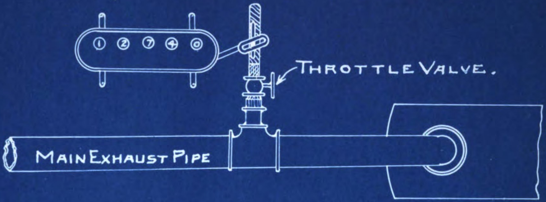
The curves on Plate [illegible] show the relation of B.H.P. to cost of running for the two engines.

Conclusion

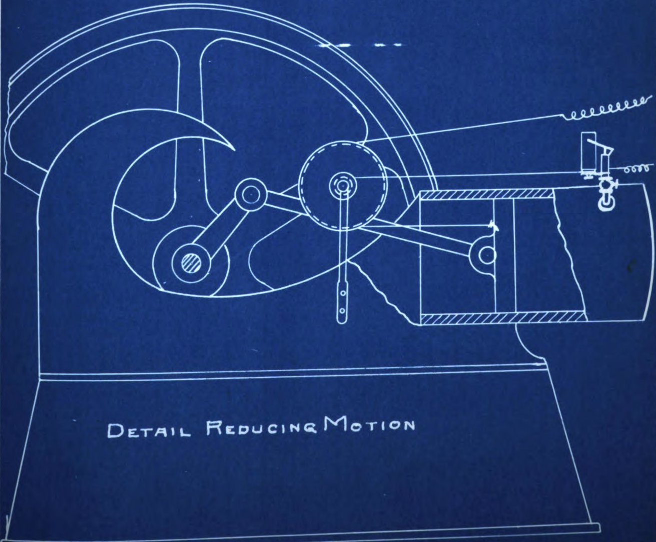
In comparing the results obtained in these tests we must remember that the steam engine was in a very poor condition, while the gasoline engine was new from the hands of the makers. The oil used in the engine was only sixty nine degrees test ~~Baumeis~~ Beaume' Scale, while the engine was rated on seventy four degrees test. This no doubt accounts for our not getting more than [illegible] B.H.P. when it was rated at 12 B.H.P. It will also be seen from the results that the gas engine costs more to operate per B.H.P. per hour. Its mechanical efficiency is about [illegible] lower, while the thermal efficiency is from 7 to [illegible] higher than the steam engine.

The gas engine costs more to run while in actual service, than the steam engine, but it needs but little attention. With the steam engine a boiler must be installed and at least one hand will be needed constantly to keep the boiler fired and the engine in proper condition. The only attention the gas engine needs is the occasional filling of the oil cup and the gasoline tank.

For intermittent work a good gas engine is no doubt the more economical and most convenient of the two engines, while for steady running the steam engine has perhaps a slight advantage. As to which is the more economical, will depend upon the conditions and circumstances under which they are to operate.



EXPLOSION COUNTER DETAIL



DETAIL REDUCING MOTION

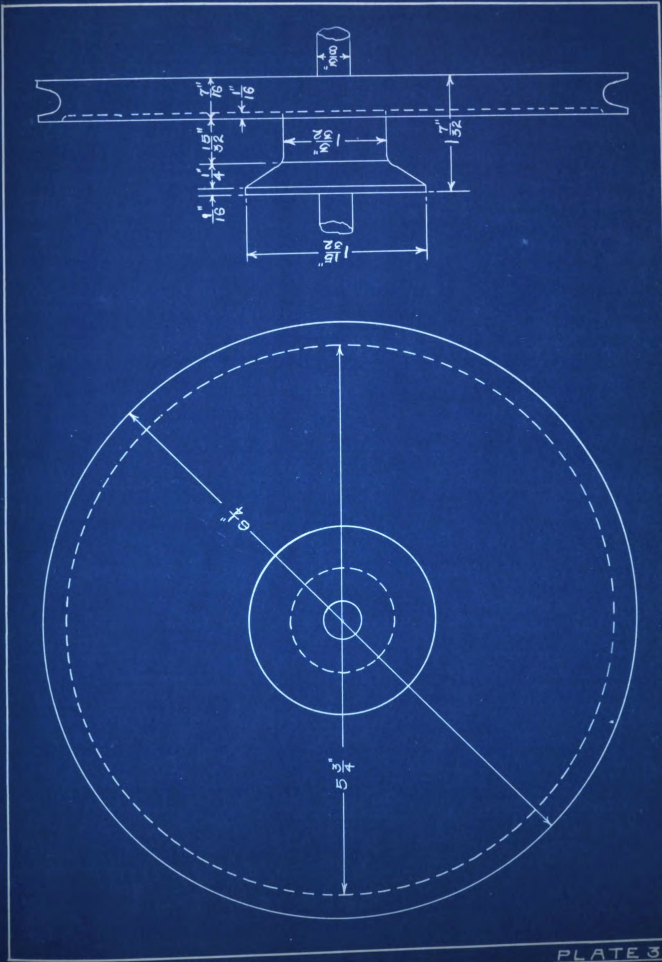


PLATE 3

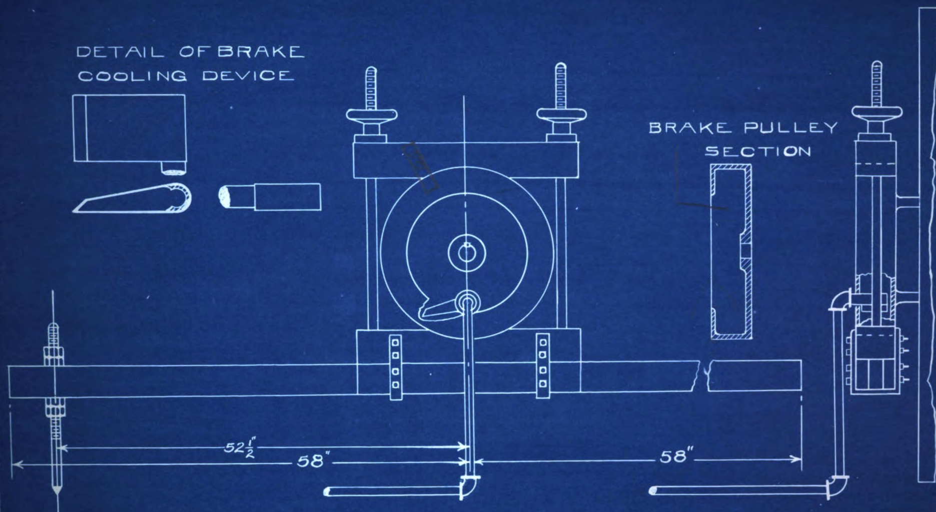

DETAIL OF BRAKE
COOLING DEVICE
BRAKE PULLEY
SECTION
52½"
58"
58"

PLATE 4.

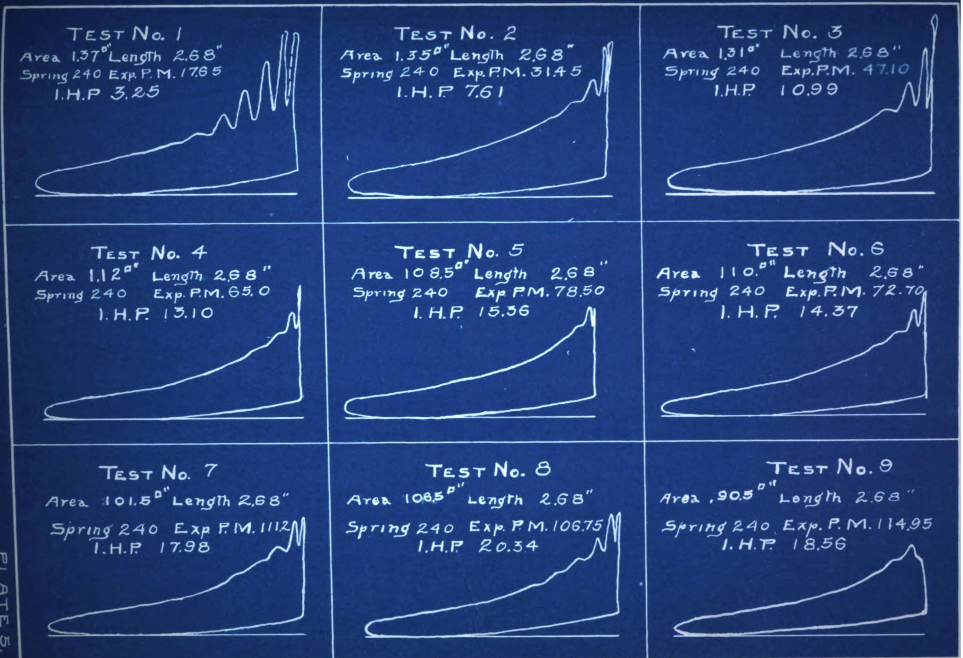

TEST No. 1
Area 1.37□" Length 2.68"
Spring 240 Exp. P. M. 17.65
I.H.P 3.25
TEST No. 2
Area 1.35□" Length 2.68"
Spring 240 Exp. P.M. 31.45
I.H.P. 7.61
TEST No. 3
Area 1.31□" Length 2.68"
Spring 240 Exp. P.M. 47.10
I.H.P. 10.99
TEST No. 4
Area 1.12□" Length 2.68"
Spring 240 Exp. P.M. 65.0
I.H.P. 13.10
TEST No. 5
Area 108.5□" Length 2.68"
Spring 240 Exp. P.M. 78.50
I.H.P. 15.36
TEST No. 6
Area 110.□" Length 2.68"
Spring 240 Exp. P.M. 72.70
I.H.P. 14.37
TEST No. 7
Area 101.5□" Length 2.68"
Spring 240 Exp P.M. 111.2
I.H.P. 17.98
TEST No. 8
Area 108.5□" Length 2.68"
Spring 240 Exp. P.M. 106.75
I.H.P. 20.34
TEST No. 9
Area .90.5□" Length 2.68"
Spring 240 Exp. P.M. 114.95
I.H.P. 18.56

PLATE 5.

COMPUTATIONS.

$$B.H.P. = \frac{4\pi LNW}{33000}$$ WHERE

L = LENGTH OF BRAKE-ARM
N = REVOLUTIONS PER. MINUTE
W = WEIGHT ON BRAKE ARM

$$I.H.P. = \frac{PLAN}{33000}$$ WHERE

P = MEAN EFFECTIVE PRESSURE
L = LENGTH OF STROKE
A = AREA OF PISTON
N = NUMBER OF EXPLOSIONS

B.T.U. SUPPLIED = 20000 B.T.U. X GASOLENE IN #

B.T.U. LOST IN JACKET WATER = WEIGHT OF COOLING WATER IN POUNDS X CHANGE IN DEGREES FAR.

$$\text{MECH. EFF.} = \frac{B.H.P.}{I.H.P.}$$

THER. EFF. = THERMAL EQUIVALENT OF BRAKE-HORSE POWER DEVELOPED ÷ BY HEAT SUPPLIED

ONE GALLON 69 TEST GASOLENE = 5.86 #

COST PER. H.P. PER. HOUR = POUNDS OF GASOLENE PER HOUR X 14¢ ÷ BY 5.86 X H.P. DEVELOPED.

NO. OF TEST	TIME		GASOLENE		TEMPERATURE OF COOLING-WATER		EXPLOSION COUNTER-READING		WT. OF COOLING WATER	WT. ON BRAKE	R.P.M.
	START	FINISH	START	FINISH	BEFORE AND	AFTER PASSING JACKET	START	FINISH			
1	3-35	3-55	16.50	15.40	52	141	75341	75694	147	0	257
2	11-20	11-40	17.50	16.00	52	75	51461	52090	620	9.41	255
3	2-10	2-30	29.25	25.50	52	85	52676	52018	420	18.83	255
4	2-40	3-00	24.00	21.00	52	84	53093	54392	500	28.29	245
5	3-25	3-45	16.50	12.00	52	94	56908	58478	444	40	240
6	10-00	10-20	28.28	19.22	54	115.5	60835	61489	245	50	242
7	11-21	11-41	19.03	14.50	52	116.5	62702	64426	300	60	241
8	1-05	1-25	25.66	19.46	52	116.5	67431	69566	299	70	241
9	1-48	2-08	21.01	13.40	52	122	71917	74216	276	79.5	240
10	3-10	3-30	32.63	27.88	53	125	10628	12946	332	80	240
11	3-20	3-40	18.54	14.33	54	114	14072	16047	399.5	70	240
12	3-50	4-10	17.89	14.10	54	114	16165	17956	395	60	241
13	4-15	4-35	13.30	10.25	54	107	18346	19828	339	50	242
14	8-05	8-25	19.90	17.30	54	118	20454	21741	257.5	40	242
15	8-40	9-00	16.56	14.34	54	120	22062	23090	210.75	30	245
16	9-05	9-25	22.61	20.72	54	105.6	23304	24146	205.75	20	250
17	9-27	9-47	20.65	19.15	54.5	97.8	24228	24907	260.25	10	255
18	4-3	4-23	14.95	13.54	52	96.5	75809	76287	194.5	0	256

LOG SHEET FOR GASENGING TEST

PLATE 7.

Test No.	Explosions Per Minute.	M.E.P.	I.H.P.	R.P.M.	Weight On Brake	B.H.P.	Mechanical Efficiency.
1	17.65	122.2	3.25	257	0	0	0
2	31.45	120.7	7.61	255	9.4	2.00	26.3
3	47.10	117.0	10.89	255	18.8	3.99	36.6
4	65.00	99.8	13.10	245	28.3	5.77	44.3
5	78.50	97.5	15.36	240	40	8.00	52.3
6	72.70	98.6	14.37	242	50	10.08	70.0
7	111.20	90.8	17.98	241	60	12.05	66.8
8	106.75	95.2	20.34	241	70	14.05	69.0
9	114.95	80.7	18.56	240	79.5	15.89	85.8
10	115.88	82.0	19.40	240	80	15.99	82.5
11	98.75	90.6	17.90	240	70	13.99	78.3
12	89.55	103.4	18.57	241	60	12.05	64.7
13	74.10	102.6	15.20	242	50	10.08	66.4
14	64.35	100.8	12.98	242	40	8.06	62.2
15	51.40	102.1	10.49	245	30	6.12	58.5
16	42.10	107.8	9.08	250	20	4.16	45.8
17	33.95	107.6	7.32	256	10	2.12	19.0
18	23.90	75.7	3.62	255	0	0	0

PLATE 8.

NO. OF TEST	TIME		GASOLENE		TEMPERATURE OF COOLING-WATER		EXPLOSION COUNTER-READING		WT. OF COOLING WATER	WT. ON BRAKE	R.P.M.
	START	FINISH	START	FINISH	BEFORE AND	AFTER PASSING JACKET	START	FINISH			
1	3-50	4-10	17.27	16.10	52	74.6	42361	42823	420	0	258
2	1-30	1-50	15.25	13.83	52	83.4	13815	14428	381.75	10	257
3	2-00	2-20	13.05	11.00	52	88.8	14577	15383	378.25	20	255
4	2-30	2-50	9.90	7.46	52	95.3	15668	16632	362	30	250
5	1-10	1-20	19.19	16.24	52	96.6	35727	36870	379	40	246
6	10-55	11-15	17.34	13.68	52	90.4	28545	29955	502.6	50	244
7	9-05	9-25	7.75	3.27	52	95.8	21291	23011	473	60	242
8	8-35	8-55	15.83	10.27	52	95.6	19107	21132	506	70	241
9	10-25	10-45	14.20	8.16	52	97.2	25883	28163	547.5	80	242
10	11-25	11-45	10.94	4.84	52	101.2	30771	33057	476	80	242
11	9-55	10-15	22.45	17.30	52	99.4	23423	25435	457.5	70	244
12	12-40	1-00	25.43	20.85	52	107.6	33747	35474	388	60	242
13	1-40	2-00	14.60	10.77	52	104.6	37143	38567	326	50	246
14	2-10	2-30	9.10	6.13	52	101.6	38837	39985	339	40	247
15	2-35	2-55	24.20	21.85	52	95.6	40042	40968	347	30	252
16	3-00	3-20	21.31	19.45	52	88.6	41071	41789	387	20	252
17	3-25	3-45	19.04	17.54	52	81.8	41837	42419	392	10	255
18	4-10	4-30	16.10	14.95	52	76.2	42823	43286	415	0	258

LOG SHEET FOR GASENGING TEST

PLATE 9.

Test No.	Explosions per Minute.	M.E.P.	I.H.P.	R.P.M.	Weight on Brake	B.H.P.	Mechanical [illegible]
1	23.10	—	—	258	0	0	—
2	30.65	—	—	257	10	2.14	—
3	40.3	—	—	255	20	4.25	—
4	48.2	—	—	250	30	6.25	—
5	57.15	108.9	12.48	246	40	8.20	65.
6	70.5	105.3	14.88	244	50	10.16	68.
7	86.0	104.2	17.97	242	60	12.10	67.
8	101.25	102.7	21.07	241	70	14.03	66.
9	114.0	86.84	19.84	242	80	16.13	81.
10	114.6	90.04	20.64	242	80	16.13	78.
11	100.6	91.2	19.18	244	70	14.23	73
12	86.35	87.7	15.20	242	60	12.10	78
13	71.2	107.5	15.41	246	50	10.25	66.
14	57.4	106.9	12.32	247	40	8.23	66.
15	46.3	—	—	252	30	6.30	—
16	35.9	—	—	252	20	4.20	—
17	29.1	—	—	255	10	2.12	—
18	23.15	—	—	258	0	0	—

PLATE. 10.

TRIAL	EXP. PER MINUTE	M.E.P.	I.H.P.	R.P.M.	WT. ON
1	23.38	73.12	3.43	257	0
2	31.28	114.12	7.16	256	1
3	42.80	112.35	9.65	253	2
4	47.20	100.93	9.56	248	3
5	57.27	103.71	13.88	244	4
6	72.10	103.49	14.97	243	5
7	86.18	96.62	16.70	242	6
8	101.84	94.93	19.40	241	7
9	114.85	89.94	19.57	241	8
1					

THIS DATA WAS OBTAINED BY

PLATE I

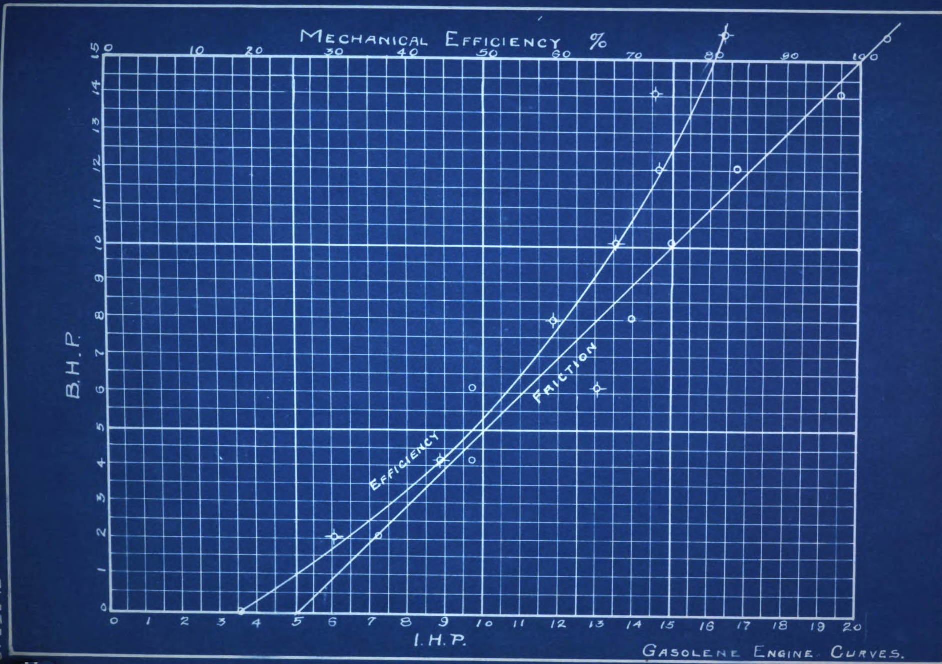
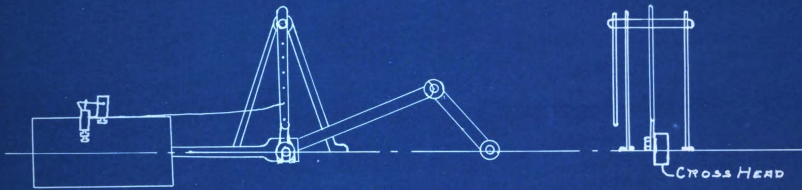

MECHANICAL EFFICIENCY %
0 10 20 30 40 50 60 70 80 90 100
B.H.P.
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
EFFICIENCY
FRICTION
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
I.H.P.
GASOLENE ENGINE CURVES.

PLATE 12.

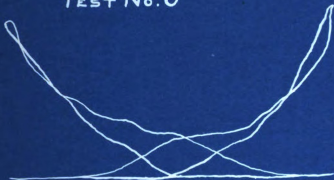


REDUCING MOTION FOR STEAM ENGINE TEST.

PLATE 14.

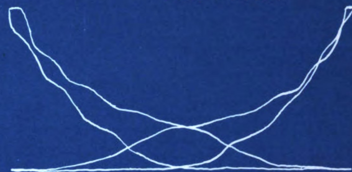
END	C.E.	SPRING	40#	END	H.E.
Area	.525□"	R.P.M.	225	Area	.305□"
Length	3.54"			Length	3.54"
I.H.P.	1.255	I.H.P. Total	2.01	I.H.P.	.755

Test No. 0



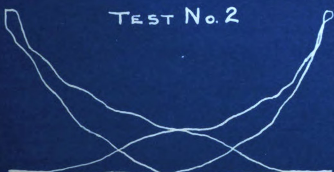
END	C.E.	SPRING	40#	END	H.E.
Area	.895	R.P.M.	225	Area	.654□"
Length	3.54			Length	3.54"
I.H.P.	2.13	I.H.P. Total	3.85	I.H.P.	1.72

Test No. 1



END	C.E.	SPRING	40#	END	H.E.
Area	1.06	R.P.M.	224	Area	.74
Length	3.54			Length	3.54
I.H.P.	2.52	I.H.P. Total	4.46	I.H.P.	1.94

Test No. 2



END	C.E.	SPRING	40#	END	H.E.
Area	1.22	R.P.M.	223	Area	1.12
Length	3.54			Length	3.54
I.H.P.	2.99	I.H.P. Total	5.73	I.H.P.	2.74

Test No. 3

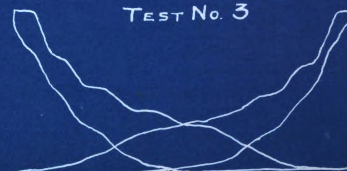
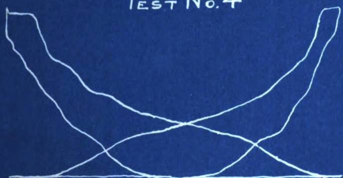


PLATE 15.

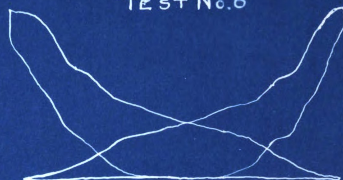
END	C.E.	SPRING	40#		END H.E.	
Area	1.41□"	R.P.M.	223		Area	1.19□"
Length	3.54"				Length	3.54"
I.H.P	3.34	I.H.P. TOTAL	6.25		I.H.P.	2.91

TEST No. 4



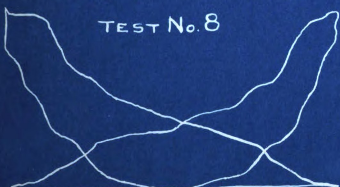
END	C.E.	SPRING	40#		END H.E.	
Area	1.81□"	R.P.M.	220		Area	1.50□"
Length	3.54				Length	3.54
I.H.P.	4.23	I.H.P. TOTAL	786		I.H.P.	3.63

TEST No. 6



END	C.E.	SPRING	40#		END H.E.	
Area	2.10□"	R.P.M.	219		Area	1.93□"
Length	3.54"				Length	3.54
I.H.P.	4.89	I.H.P. TOTAL	9.53		I.H.P.	4.64

TEST No. 8



END	C.E.	SPRING	40#		END H.E.	
Area	2.66	R.P.M.	217		Area	2.62
Length	3.54				Length	3.54
I.H.P.	6.35	I.H.P. TOTAL	12.67		I.H.P.	6.22

TEST No. 11

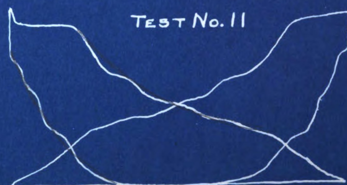


PLATE 16.

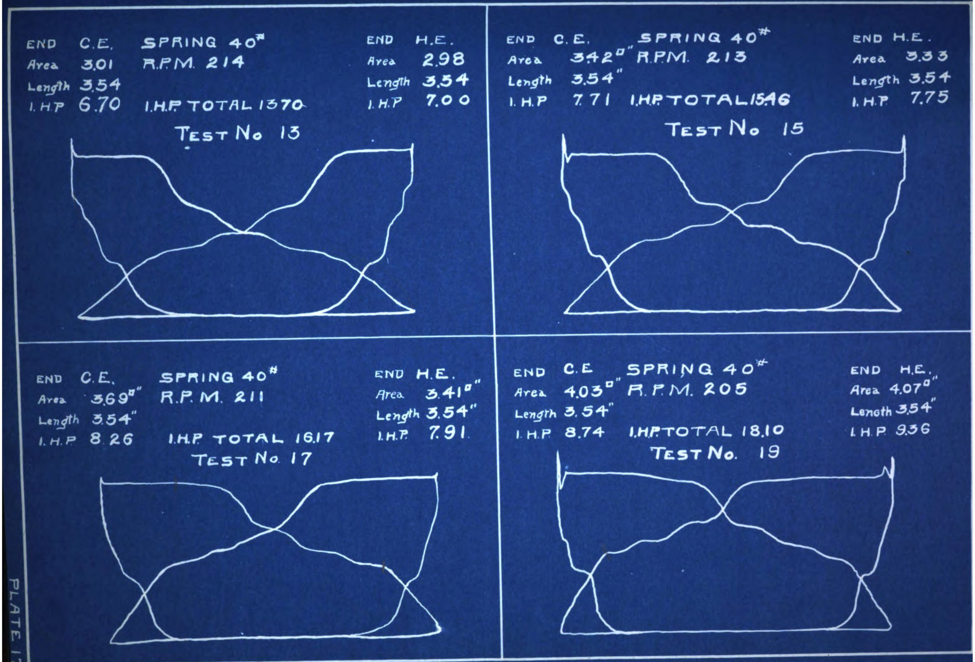

END C.E. SPRING 40#
Area 3.01 R.P.M. 214
Length 3.54
I.H.P 6.70 I.H.P. TOTAL 1370
END H.E.
Area 2.98
Length 3.54
I.H.P 7.00
TEST No 13
END C.E. SPRING 40#
Area 3.42□" R.P.M. 213
Length 3.54"
I.H.P 7.71 I.H.P. TOTAL 15.46
END H.E.
Area 3.33
Length 3.54
I.H.P 7.75
TEST No 15
END C.E. SPRING 40#
Area 3.69□" R.P.M. 211
Length 3.54"
I.H.P 8.26 I.H.P. TOTAL 16.17
END H.E.
Area 3.41□"
Length 3.54"
I.H.P. 7.91
TEST No. 17
END C.E SPRING 40#
Area 4.03□" R.P.M. 205
Length 3.54"
I.H.P 8.74 I.H.P. TOTAL 18.10
END H.E.
Area 4.07□"
Length 3.54"
I.H.P 9.36
TEST No. 19

PLATE 17.

FORMULAE.

$$B.H.P. = \frac{2\pi L.N.P.}{33000}$$

L = LENGTH OF BRAKE ARM IN FEET = $4\frac{1}{16}'$

N = R.P.M.

P = WEIGHT AT END OF BRAKE ARM

$\frac{2\pi L}{33000}$ = BRAKE CONSTANT = .0007735 (a)

TOTAL I.H.P. =

I.H.P. AT HEAD END + I.H.P. AT CRANK END.

$$I.H.P. = \frac{PLAN}{33000}$$

P = M.E.P.

L = LENGTH OF STROKE IN FEET = $\frac{5'}{6}$

A = PISTON AREA IN SQUARE INCHES
= HEAD END — $\frac{49}{4}\pi$
= CRANK END — $\left(\frac{49}{4} - \frac{25}{64}\right)\pi$

N = R.P.M.

DIAMETER PISTON ROD = $\frac{5''}{8}$

$\frac{LA}{33000}$ = ENGINE CONSTANT

= HEAD END;— .0009718

= CRANK END;— .0009400

I.H.P. = HEAD END;— .0009718 P.N. (b)

= CRANK END;— .0009400 P.N. (c)

$$M.E.P. = \frac{A.S.}{L}$$ (d)

A = CARD AREA IN SQUARE INCHES

L = " LENGTH IN INCHES

S = 40 = SCALE OF INDICATOR SPRING.

FORMULAE.

THE PERCENT OF DRY STEAM $x =$

$$= \frac{\lambda_1 + c_p(t_s - t_1) - q}{r} \qquad (e)$$

$c_p = .4805$

p_1 = PRESSURE IN CALORIMETER

λ_1 = TOTAL HEAT (STEAM TABLES)

t_1 = TEMPERATURE (STEAM TABLES)

t_s = TEMPERATURE IN CALORIMETER.

q = HEAT OF LIQUID (STEAM TABLES.)

r = HEAT OF VAPORIZATION (STEAM TABLES.)

THE MECHANICAL EFFICIENCY.

$$= \frac{B.H.P.}{I.H.P.} \qquad (f)$$

THE THERMAL EFFICIENCY.

$$= \frac{\text{THERMAL EQUIVALENT OF B.H.P.}}{\text{TOTAL B.T.U. SUPPLIED}}$$

$$= \frac{2545.2\ B.H.P.}{\lambda H x + q H(1-x)} \qquad (g)$$

λ = TOTAL HEAT.

H = POUNDS OF STEAM CONDENSED.

q = HEAT OF LIQUID.

x = % DRY STEAM.

THE AMOUNT OF DRY STEAM USED PER B.H.P. PER HOUR.

$$= \frac{Hx}{B.H.P.} \qquad (h)$$

THE COST PER B.H.P. PER HOUR IS FIGURED ON THE ASSUMPTION THAT ONE POUND OF COAL WILL EVAPORATE 7 POUNDS OF WATER AND THAT THE COAL USED COST \$3.00 PER TON

$$= \frac{300 \times \text{POUNDS STEAM USED PER B.H.P. PER HOUR}}{2000 \times 7} \qquad (j)$$

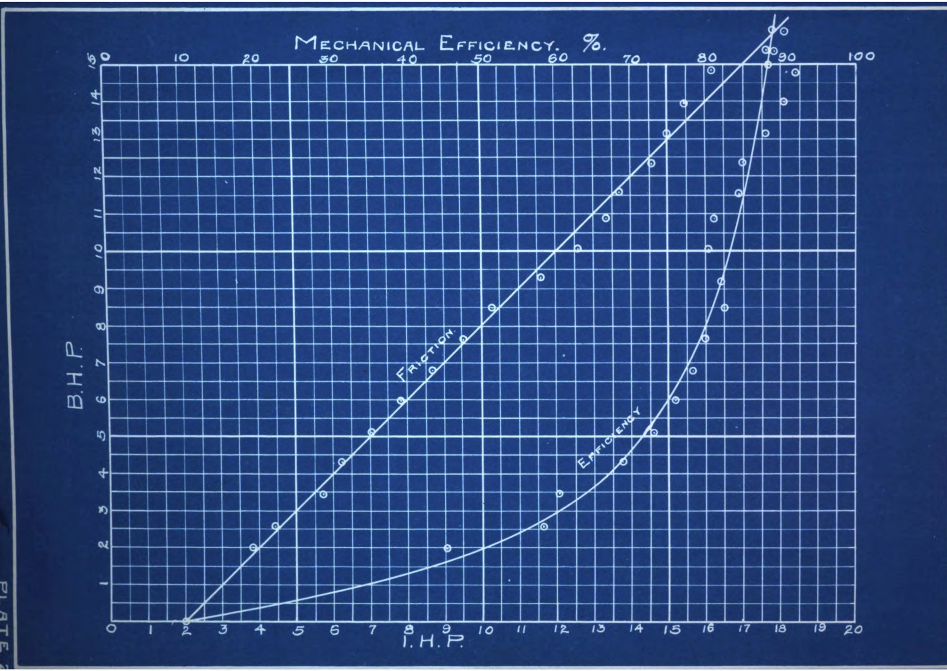
= COST IN CENTS PER B.H.P. PER HOUR.

Data For Mechanical Efficiency
Test On Steam Engine.

Test No.	R.P.M.	Card Data			M.E.P.		I.H.P.			Weight On Brake	B.H.P.	Mechanical Efficiency
		Length	Area									
			C.E.	H.E.	C.E.	H.E.	C.E.	H.E.	Total			
0	225	3.54	.525	.305	5.94	3.46	1.255	.755	2.01	0	0	0
1	225	3.54	.895	.654	10.15	7.40	2.13	1.72	3.85	10	1.74	45.2
2	224	3.54	1.06	.740	11.95	8.37	2.52	1.94	4.46	15	2.60	58.2
3	223	3.54	1.22	1.12	13.8	12.65	2.99	2.74	5.73	20	3.45	60.2
4	223	3.54	1.41	1.19	15.95	13.45	3.34	2.91	6.25	25	4.31	69.0
5	221	3.54	1.56	1.39	17.65	15.75	3.66	3.37	7.03	30	5.13	73.1
6	220	3.54	1.81	1.50	20.5	16.9	4.23	3.63	7.86	35	5.96	75.9
7	220	3.54	1.89	1.77	21.4	20.0	4.42	4.28	8.70	40	6.81	78.4
8	219	3.54	2.10	1.93	23.7	21.8	4.89	4.64	9.53	45	7.65	80.3
9	219	3.54	2.21	2.15	25.0	24.3	5.14	5.16	10.30	50	8.50	82.5
10	218	3.54	2.56	2.37	28.9	26.8	5.94	5.67	11.61	55	9.30	82.4
11	217	3.54	2.66	2.62	30.1	29.6	6.35	6.22	12.57	60	10.07	80.3
12	216	3.54	2.95	2.84	33.3	32.1	6.62	6.74	13.36	65	10.86	81.4
13	214	3.54	3.01	2.98	34.1	33.7	6.70	7.00	13.70	70	11.58	84.5
14	213	3.54	3.17	3.16	35.8	35.7	7.17	7.40	14.57	75	12.36	85.0
15	212	3.54	3.31	3.22	38.6	37.6	7.50	7.45	14.95	80	13.12	87.8
16	212	3.54	3.45	3.35	39.0	37.8	7.77	7.64	15.41	85	13.94	90.5
17	211	3.54	3.69	3.41	41.8	38.5	8.26	7.91	16.17	90	14.86	91.9
18	209	3.54	3.92	3.98	44.3	45.0	8.68	9.15	17.83	95	15.35	86.0
19	205	3.54	4.07	4.03	45.5	46.1	8.74	9.36	18.10	100	15.85	87.6

Engine Constants H.E.=.000972 C.E.=.000940 Brake Constant .0007635

Plate 20



MECHANICAL EFFICIENCY. %.
0
10
20
30
40
50
60
70
80
90
100
B.H.P.
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
FRICTION
EFFICIENCY
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
I.H.P.

PLATE 2

Log Steam Engine Economy Test.

Test No.	Time		Manometer Readings (Pressures in Steam Chamber In's. Mercury)			Temperature of Steam Chamber.	Barometric Pressure. Inches of Mercury.	Pressure in Steam Main.	R.P.M.	Weight of Condensed Steam.
	Start	Finish	Right +	Left −	Total					
1	10.55	11.15	3.3	3.5	6.8	259	29.20	77.0	225	110.25
2	11.28	11.48	3.4	3.6	7.0	258	29.21	76.3	225	165.
3	9.10	9.30	2.9	2.8	5.7	257	29.71	78.3	222	151.
4	9.50	10.10	2.6	2.7	5.3	254	29.71	75.6	221	164.5
5	10.15	10.35	2.5	2.6	5.1	254	29.71	74.9	220	169.
6	10.50	11.10	2.5	2.6	5.1	252	29.71	74.4	220	173.5
7	11.40	12.00	2.5	2.7	5.2	250	29.70	75.6	218	200.
8	1.00	1.20	2.5	2.6	5.1	251	29.68	75.0	218	212.
9	1.25	1.45	2.9	3.1	6.0	256	29.68	75.0	216	214.5
10	2.00	2.20	2.8	3.0	5.8	255	29.68	73.4	212	233.
11	2.45	3.05	3.0	3.1	6.1	255	29.69	74.2	211	243.
12	3.20	3.40	3.1	3.2	6.3	254	29.69	73.8	210	253.

Steam Engine Economy Test.

Carpenter Throttling Calorimeter Test Of Steam.

Test No.	Barometric Pressure.	Presure In Steam Chamber			λ_1	t_1	Temperature Steam Chamber			Pressure In Steam Main				q	r	Quality of Steam x = %
		Inches Mercury	Pounds Per Sq. In.	Corrected Pressure	(Steam	Tables)	Thermom Reading	Error −	Corrected Reading	Gauge Reading	Error +	Corrected Reading	Corrected Pressure	(Steam	Tables)	
1	14.33	6.8	3.34	17.67	1149.5	221.5	259	2.5	261.5	77.0	4	73.0	87.33	278.8	891.1	98.85
2	14.34	7.0	3.41	17.75	1149.6	221.7	258	2.5	260.5	76.3	4	72.3	86.64	267.2	891.5	98.82
3	14.58	5.7	2.82	17.40	1149.3	220.6	257	2.5	259.5	78.3	4	74.3	88.88	289.1	890.2	98.73
4	14.59	5.3	2.60	17.19	1149.1	220.0	254	2.5	256.5	75.6	4	71.6	86.19	286.9	891.8	98.35
5	14.58	5.1	2.50	17.08	1149.0	219.7	254	2.5	256.5	74.9	4	70.9	85.48	286.2	892.2	98.68
6	14.58	5.1	2.50	17.08	1149.0	219.7	252	2.5	254.5	74.4	4	70.4	84.98	285.8	892.5	98.64
7	14.58	5.2	2.56	17.14	1149.0	219.9	250	2.5	252.5	75.6	4	71.6	86.18	286.9	891.8	98.42
8	14.58	5.1	2.50	17.08	1149.0	219.7	251	2.5	253.5	75.0	4	71.0	85.58	286.3	892.2	98.51
9	14.58	6.0	2.94	17.52	1149.4	221.0	256	2.5	258.5	75.0	4	71.0	85.58	286.3	892.2	98.75
10	14.57	5.8	2.87	17.44	1149.4	220.7	255	2.5	257.5	73.4	4	69.4	83.97	285.0	893.1	98.72
11	14.58	6.1	3.00	17.58	1149.5	221.2	255	2.5	257.5	74.2	4	70.2	84.78	285.6	892.7	98.72
12	14.58	6.3	3.08	17.66	1149.5	221.4	254	2.5	256.5	73.8	4	69.8	84.38	285.3	892.9	98.68

STEAM ENGINE E

TEST No.	TOTAL WT. STEAM	WEIGHT OF DRY STEAM.	WEIGHT OF WET STEAM	CORRECTED PRESSURE IN STEAM MAIN.	λ (STEAM TABLES.)	q (STEAM TABLES.)	TOT SUP
1	331	327.2	3.8	87.34	1178.9	287.8	386
2	495	489.2	5.8	86.64	1178.7	287.2	57
3	453	447.2	5.8	88.89	1179.3	289.1	52
4	493.5	485.4	8.1	86.18	1178.6	286.9	57
5	507	500.3	6.7	85.48	1178.4	286.2	59
6	520.5	513.4	7.1	84.98	1178.3	285.8	60
7	600	591.5	9.5	86.18	1178.6	286.9	69
8	636	626.6	9.4	83.57	1178.5	286.3	74
9	643.5	635.5	8.0	85.57	1178.5	286.3	75
10	699.	690.0	9.0	84.97	1178.3	285.8	81
11	729	719.7	9.3	84.77	1178.2	285.6	85
12	759	749.0	10.0	84.37	1178.1	285.3	88

PLATE 25.

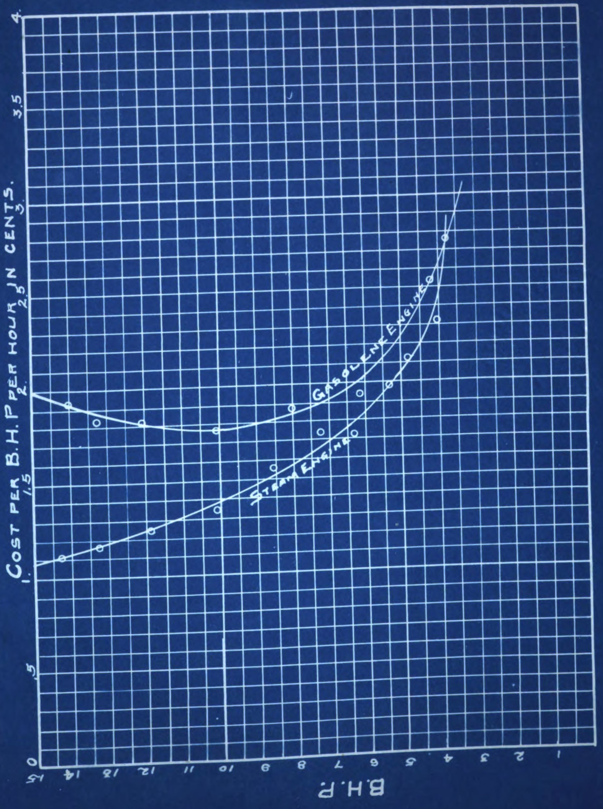

COST PER B.H.P PER HOUR IN CENTS.
B.H.P
GASOLENE ENGINE
STEAM ENGINE
0
.5
1.
1.5
2.
2.5
3.
3.5
4.
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1

PLATE 26.