Union Pacific Railroad Company
Research & Mechanical Standards

REPORT OF TESTS

Locomotive 4007
Equipped with single stack, annular ported exhaust nozzle and Master Mechanic's front end arrangement

Locomotive 4010
Equipped with double stack, multiple jet nozzles and modified Master Mechanic's front end arrangement

October 10-26, 1948

Office of
Gen'l Supt. MP&M
Omaha, March 9, 1949

Union Pacific Railroad Company
Research & Mechanical Standards

SUMMARY OF TEST RESULTS

between
Cheyenne & Laramie

	Westbound		Eastbound		Eastbound and Westbound-Combined	
Locomotive No.	4007	4010	4007	4010	4007	4010
No. of Trips	4	4	5	4	9	8
Ave. No. of Stops Per Trip	3.25	1.50	4.20	3.50	3.73	2.50
Ave. Running Time	2'48"	2'35"	2'14"	2' 5"	2'42"	2'10"
Ave. Speed MPH	20.3	22.0	25.6	27.4	23.0	24.7
Ave. Tons Per Trip	2611	2681	3920	3906	3266	3294
Ave. MGTM Per Trip	148.30	152.28	222.66	221.86	189.61	187.07
Ave. Coal Pounds Per Trip	41882	33134	25667	23270	32874	28202
Ave. Coal Per MGTM	282.4	217.6	115.3	104.9	198.85	161.25
Percent Increase in Fuel Consumption	29.8	-	9.9	-	23.3	-
Max. Indicated Horsepower	4346	5078	4333	5503	4346	5503

Draft in inches of water at front flue sheet for following back pressures:						
10					8.1	11.7
12					9.1	13.8
14					9.9	15.5
16					10.5	16.9
18					11.2	18.1
Temperature °F. steam to cylinders at following back pressures:						
12					651	707
14					667	723
16					678	733

The results of this test show the desirability of using the double stack, multiple jet exhaust nozzles and modified Master Mechanic's front end arrangement for drafting 4000 class locomotives.

Locomotive 4010, which is equipped with the double stack arrangement, was used for comparison with locomotive 4007, which is equipped with a single stack, annular ported exhaust nozzle and Master Mechanic's front end arrangement.

The front end arrangement on locomotive 4010 includes a 45-degree deflector plate extending forward and upward from the bottom of an 18-inch strip of netting across the back plate. With this deflector plate the front end has proven to be a very effective spark arrester and can be considered satisfactory in this respect.

The above summary shows some of the more important results of this test and indicates higher front end efficiency and better overall efficiency for locomotive 4010.

Averages are based on complete trips between Cheyenne and Laramie.

Indicated horsepower is taken from Table VII, temperature of steam to cylinders is from Figure No. 3 and draft in inches of water from Figure No. 12.

<u>LOCOMOTIVES</u>

The important locomotive dimensions are shown in the following tabulation:

General classification	4-8-8-4
Service	Freight
Starting tractive force, pounds	135,375
Weight locomotive in working order, pounds	762,000
Weight locomotive light, pounds	697,300
Weight tender light, pounds	171,500
Weight tender loaded, pounds	427,500
Weight locomotive and tender loaded, pounds	1,189,500
Tender water capacity, gallons	24,000
Tender coal capacity, tons	28
Expansion of steam	Single
Number of cylinders	4
Cylinder diameter, inches	23-3/4
Cylinder stroke, inches	32
Valve gear	Walschaerts

VALVES:

Diameter, inches	12
Full gear travel, inches	7
Lap, inches	1-3/8
Lead, inches	1/4
Exhaust clearance, inches	1/8

BOILER:

Working pressure, pounds per square inch gage	300
Length tubes and flues, feet, inches	22'0"
Number of 2-1/4 inch diameter tubes	75
Number of 4-inch diameter flues	184

FIREBOX:

Length, inches	235-1/32
Width, inches	96-3/16
Grate area, square feet	150
Number of Security Circulators	7
Percent air opening grates	12

HEATING SURFACE, Square Feet:

Firebox and combustion chamber	593
Circulators	111
Boiler tubes	967
Boiler flues	4218
Total evaporative heating surface	5889
Superheater heating surface	2466
Total heating surface	8355

TERRITORY AND TRAINS:

Tests were run in both directions between Cheyenne and Laramie. All tests were made in freight service and with one exception all westbound trips were made without a helper locomotive. Trains hauled were representative of the regular freight movement.

DATA:

All data necessary for the determination of boiler, cylinder and exhaust steam injector performance were taken.

Coal consumption was determined by counting the revolutions made by the stoker conveyor screw. This was done by means of an odometer operated by a device driven by the conveyor screw. The amount of coal delivered per revolution was determined by emptying a tank which had been filled to the specified capacity of 56,000 lbs. of coal and counting the revolutions required. A number of checks were made and an average coal factor determined which could be applied to all Standard MB stokers. This factor of 8 pounds per revolution checks very closely with data from the Standard Stoker Company.

This method of measuring coal is considered more accurate than the method formerly used of measuring coal space volume, where small errors in measurement may cause errors of several hundred pounds in determining the weight of coal used.

Tank water consumption was determined by measuring the water in the tank at the start of a run, before and after taking water and at the end of a run.

A continuous record was kept of the time the exhaust steam injector was operating on exhaust steam, on live steam and when shut off. A venturi meter was applied to the water intake line of the exhaust steam injector. With this device the rate at which tank water was being fed to the boiler could be determined at any time, and the amount of tank water delivered on live steam operation was calculated from the injector time log. For accurate timing of the injector operation an automatic signal was devised which indicated when the injector was started, when it changed from live steam operation to exhaust steam operation, from exhaust steam operation to live steam operation and when the injector was shut off.

A record was kept of the train movement, tonnage and number of cars.

The following pressures were observed and recorded:

1. Boiler
2. Valve chamber
3. Exhaust nozzle stand
4. Exhaust steam in injector
5. Live steam to injector

The following temperatures were observed and recorded:

1. Tank water
2. Delivery water
3. Steam to right cylinders
4. Steam to left cylinders
5. Exhaust steam from right back cylinder
6. Exhaust steam from left back cylinder
7. Exhaust steam from front engine.
8. Smoke box gases right side
9. Smoke box gases left side

Draft was measured near the top and bottom of the smoke box, approximately one foot ahead of the front flue sheet.

A speed recorder was used to indicate and record the speed and to correlate temperature and pressure readings with the speed. Correlation of all readings with speed was accomplished by marking the speed recorder tape before and after taking each set of readings. By this procedure it is possible to calculate indicated horsepower for each reading and make an accurate comparison with theoretical horsepower-speed curves. These records may also be used in conjunction with the condensed profile to show the speed and required back pressure at any desired point with a given train.

COMPILED DATA AND GRAPHICAL PRESENTATION:

The data taken during the tests and the calculated results are shown in charts and tables compiled under the following headings:

Table I	General Performance
Table II	Fuel - Water - Evaporation
Table III	Average Pressures and Temperatures
Table IV	Evaporation and Temperature Rise due to Exhaust Steam Condensed by Exhaust Steam Injector
Table V	Elesco Exhaust Steam Injector Performance
Table VI	Fuel Saved by Operation of Elesco Exhaust Steam Injector
Table VII	Water Rates and Indicated Horsepower

The following curves are included:

Figure 1	Relation between Firing Rate and Boiler Heat Absorption Rate

GENERAL PERFORMANCE:

At the time of the test the locomotives had comparable flue miles, machinery and appurtenances were in generally good condition, and valves were set as nearly as possible the same on both locomotives. The essential difference in the locomotives was, therefore, in the front end arrangement and admission of overfire air in the firebox.

Locomotive 4007 was equipped with a single stack, annular ported exhaust nozzle and Master Mechanic's front end arrangement.

Locomotive 4010 was equipped with double stacks, multiple jet exhaust nozzle and modified Master Mechanic's front end. Overfire air was admitted in the firebox through twenty-eight 2-1/4" tubes.

The general performance of locomotives 4007 and 4010 is shown clearly on charts I to VIII on which are presented the speed recorder tapes arranged with a condensed profile of the territory over which the tests were run. From the time checks on the recorder tapes it is possible to accurately correlate data such as speed, gradient, back pressure and indicated horsepower.

In Tables I, II, III and VII data are tabulated which show the comparative performance of the two locomotives.

Because of the long descending grades both eastbound and westbound from Sherman, each test run was closed out at Sherman. All totals and averages are, therefore, more nearly representative of the general performance of the locomotives than if the entire run between Cheyenne and Laramie had been included.

The superior performance of locomotive 4010 is shown both on the speed recorder tapes and in Figures 5, 6, 7, 8, 9, 10 and 11.

<u>EXHAUST STEAM INJECTOR PERFORMANCE</u>:

Both injectors performed satisfactorily although it was necessary to replace the size 19 tubes in the injector on locomotive 4007 with smaller size 18 tubes. This was because of the reduced capacity of the engines after the application of the annular ported exhaust nozzle. The better performance characteristics of the exhaust injector of locomotive 4010 shown in Figure 4 are due to the higher temperatures of the exhaust steam recovered.

<u>BOILER PERFORMANCE</u>:

Boiler performances are shown in Figure 1. The better heat absorption rate of the boiler of locomotive 4010 is due to better combustion of fuel and less stack loss. This is due to the use of overfire air and a more efficient front end arrangement. At a given firing rate, the heat absorption rate of identical boilers should be the same, providing the fuel is utilized. The difference in unburned fuel loss is, therefore, responsible for the difference in boiler heat absorption rate at a given firing rate.

FRONT END PERFORMANCE:

Figure 12 shows clearly the greater efficiency of the front end arrangement in locomotive 4010. It is interesting to note the small difference in draft from top to bottom of the flue sheets and especially in locomotive 4007 with a low table plate. The vertical draft distribution is good as shown by draft readings and although readings were not taken on the horizontal center line of the boiler, it is reasonable to assume good distribution horizontally.

The draft at the front flue sheet in locomotive 4010 is greater than that in locomotive 4007 by 50% at 10 PSI exhaust stand pressure to 61.8% greater at 17 PSI exhaust stand pressure.

DISCUSSION OF FRONT END ARRANGEMENTS:

The important front end dimensions are shown by following tabulation:

	Locomotive 4007	Locomotive 4010
Type nozzle	Annular ported	Multiple jet
Nozzle area	Trip Oct. 10 - 49.5 sq. in. (16-3/4" OD and 10-5/8" dia. plate) Other trips - 46.9 sq. in. (16-3/4" OD and 11" dia. plate)	56.5 sq. in. (8 - 3" dia. nozzles)
Vertical distance - nozzle tip to seat on exhaust base	26-1/2"	16-3/4"
Vertical distance - nozzle tip to bottom of stack extension	15-1/4"	10-1/32"
Total length stack including extension	51"	66"
Inside diameter stack at choke	27"	23-3/4"

	Locomotive 4007	Locomotive 4010
Inside diameter stack at top	29"	28-3/4"
Type of front end arrangement	Master Mechanics	Modified Master Mechanics
Table plate	2-1/2 x 2-1/2 netting	Solid plate
Back plate	Solid plate	Plate with 18" strip of 2-1/2 X 2-1/2 netting
Net gas area through tubes and flues		
At superheater return bend	1435 sq. in.	1435 sq. in.
At front flue sheet	1675 sq. in.	1675 sq. in.
Net area through front end arrangement	1740 sq. in.	1929 sq. in.
Area of stacks at top	661 sq. in.	1298 sq. in.
Area of stacks at choke	573 sq. in.	886 sq. in.
Ratio of stack choke area to nozzle area	12.2	15.7
Perimeter of exhaust steam jet at nozzle	69.0 in.	75.4 in.

For a given locomotive and any given front end arrangement, which includes stack and exhaust nozzle, there is a definite upper limit of output of the locomotive at which the weight of air supplied will equal that required for the fuel burned. Below this limit the percentage of excess air will increase with decreasing locomotive output, above this limit there will be a deficiency of air. The position of the limits is determined by the characteristics of the engine boiler and of the front end arrangement.

With locomotives of the same design which have the same resistance to gas flow through the tubes, flues and firebox, the number of inches of water draft per pound of cylinder back pressure or exhaust stand pressure, when measured in the same relative position near the front flue sheet, may be used as the criterion of the performance of front end arrangements.

The entrainment ratio, which is the ratio of the weight of gases moved to the weight of steam required to move the gases, of a front end arrangement, increases with decreased back pressure, decreased front end resistance and increased ratio of stack area to nozzle area.

As shown in the above tabulation, the annular ported exhaust nozzle of 49.5 sq. inches was used only on one test run. The area was then reduced to 46.9 sq. inches to improve the steaming qualities of the locomotive. The multiple jet exhaust nozzle compared with the annular ported exhaust nozzle has 20.5 percent greater area and due to a better coefficient of discharge will pass 24.6 percent more steam at a given back pressure. This means that more flue gas can be moved at a given back pressure. Also, either the same power may be developed on less back pressure or more power may be developed on the same back pressure.

The net area through the front end arrangement is 10.9 percent greater in locomotive 4010 than in locomotive 4007. It, therefore, offers less resistance and permits easier flow of gases and consequently less energy is needed to move the required amount of gases through the front end.

The larger ratio of stack to nozzle area of locomotive 4010 also helps increase the entrainment ratio of the front end.

Other front end dimensions although of lesser importance also serve to give the front end arrangement of locomotive 4010 a higher entrainment ratio than the front end arrangement of locomotive 4007.

Since the characteristics of engines and boilers of the two test locomotives are essentially the same, maximum output of the locomotives will be limited by the front end arrangements, and differences of maximum output will be attributable to differences in front end arrangements.

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Office of
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Omaha, February 21, 1949

SUMMARY OF RESULTS OF TEST

This test shows the desirability of using the double stack, multiple jet exhaust nozzles and modified Master Mechanic's front end arrangement for the drafting of 4000 class locomotives.

This front end arrangement includes a 45-degree deflector plate extending forward and upward from the bottom of an 18-inch strip of netting across the back plate. With this deflector plate the front end has proven to be a very effective spark arrester and can be considered entirely satisfactory in this respect. Higher front end efficiency was indicated as shown by:

1. Higher drafts for a given back pressure.

2. Higher efficiency of combustion of the coal.

3. Higher cylinder efficiency by reduction of cylinder back pressures and increased superheated steam temperatures.

4. Less coal fired per thousand gross ton miles.

LOCOMOTIVES

The important locomotive dimensions are shown in the following tabulation:

General classification	4-8-8-4
Service	Freight
Starting tractive force, pounds	135,375
Weight locomotive in working order, pounds	762,000
Weight locomotive light, pounds	697,300
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Weight tender loaded, pounds	427,500
Weight locomotive and tender loaded, pounds	1,189,500
Tender water capacity, gallons	24,000
Tender coal capacity, tons	28
Expansion of steam	Single
Number of cylinders	4
Cylinder diameter, inches	23-3/4
Cylinder stroke, inches	32
Valve gear	Walschaerts

VALVES:

Diameter, inches	12
Full gear travel, inches	7
Lap, inches	1-3/8
Lead, inches	1/4
Exhaust clearance, inches	1/8

BOILER:

Working pressure, pounds per square inch gage	300
Length tubes and flues, feet, inches	22'0"
Number of 2-1/4 inch diameter tubes	75
Number of 4-inch diameter flues	184

FIREBOX:

Length, inches	235-1/32
Width, inches	96-3/16
Grate area, square feet	150
Number of Security Circulators	7
Percent air opening grates	12

HEATING SURFACE, Square Feet:

Firebox and combustion chamber	593
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At the time of the test the locomotives had comparable flue miles, machinery and appurtenances were in generally good condition, and valves were set as nearly as possible the same on both locomotives. The essential difference in the locomotives was, therefore, in the front end arrangement and admission of overfire air in the firebox.

Locomotive 4007 was equipped with a single stack, annular ported exhaust nozzle and Master Mechanic's front end arrangement.

Locomotive 4010 was equipped with double stacks, multiple jet exhaust nozzle and modified Master Mechanic's front end. Overfire air was admitted in the firebox through twenty-eight 2-1/4" tubes.

The general performance of locomotives 4007 and 4010 is shown clearly on charts I to VIII on which are presented the speed recorder tapes arranged with a condensed profile of the territory over which the tests were run. From the time checks on the recorder tapes it is possible to accurately correlate data such as speed, gradient, back pressure and indicated horsepower.

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The superior performance of locomotive 4010 is shown both on the speed recorder tapes and in Figures 5, 6, 7, 8, 9, 10 and 11.

EXHAUST STEAM INJECTOR PERFORMANCE:

Both injectors performed satisfactorily although it was necessary to replace the size 19 tubes in the injector on locomotive 4007 with smaller size 18 tubes. This was because of the reduced capacity of the engines after the application of the annular ported exhaust nozzle. The better performance characteristics of the exhaust injector of locomotive 4010 shown in Figure 4 are due to the higher temperatures of the exhaust steam recovered.

BOILER PERFORMANCE:

Boiler performances are shown in Figure 1. The better heat absorption rate of the boiler of locomotive 4010 is due to better combustion of fuel and less stack loss. This is due to the use of overfire air and a more efficient front end arrangement. At a given firing rate, the heat absorption rate of identical boilers should be the same, providing the fuel is utilized. The difference in unburned fuel loss is, therefore, responsible for the difference in boiler heat absorption rate at a given firing rate.

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DISCUSSION OF FRONT END ARRANGEMENTS:

The important front end dimensions are shown by following tabulation:

	Locomotive 4007	Locomotive 4010
Type nozzle	Annular ported	Multiple jet
Nozzle area	Trip Oct. 10 - 49.5 sq. in. (16-3/4" OD and 10-5/8" dia. plate) Other trips - 46.9 sq. in. (16-3/4" OD and 11" dia. plate)	56.5 sq. in. (8 - 3" dia. nozzles)
Vertical distance - nozzle tip to seat on exhaust base	26-1/2"	16-3/4"
Vertical distance - nozzle tip to bottom of stack extension	15-1/4"	10-1/32"
Total length stack including extension	51"	66"
Inside diameter stack at choke	27"	23-3/4"

	Locomotive 4007	Locomotive 4010
Inside diameter stack at top	29"	28-3/4"
Type of front end arrangement	Master Mechanics	Modified Master Mechanics
Table plate	2-1/2 x 2-1/2 netting	Solid plate
Back plate	Solid plate	Plate with 18" strip of 2-1/2 X 2-1/2 netting
Net gas area through tubes and flues		
At superheater return bend	1435 sq. in.	1435 sq. in.
At front flue sheet	1675 sq. in.	1675 sq. in.
Net area through front end arrangement	1740 sq. in.	1929 sq. in.
Area of stacks at top	661 sq. in.	1298 sq. in.
Area of stacks at choke	573 sq. in.	886 sq. in.
Ratio of stack choke area to nozzle area	12.2	15.7
Perimeter of exhaust steam jet at nozzle	69.0 in.	75.4 in.

For a given locomotive and any given front end arrangement, which includes stack and exhaust nozzle, there is a definite upper limit of output of the locomotive at which the weight of air supplied will equal that required for the fuel burned. Below this limit the percentage of excess air will increase with decreasing locomotive output, above this limit there will be a deficiency of air. The position of the limits is determined by the characteristics of the engine boiler and of the front end arrangement.

With locomotives of the same design which have the same resistance to gas flow through the tubes, flues and firebox, the number of inches of water draft per pound of cylinder back pressure or exhaust stand pressure, when measured in the same relative position near the front flue sheet, may be used as the criterion of the performance of front end arrangements.

The entrainment ratio, which is the ratio of the weight of gases moved to the weight of steam required to move the gases, of a front end arrangement, increases with decreased back pressure, decreased front end resistance and increased ratio of stack area to nozzle area.

As shown in the above tabulation, the annular ported exhaust nozzle of 49.5 sq. inches was used only on one test run. The area was then reduced to 46.9 sq. inches to improve the steaming qualities of the locomotive. The multiple jet exhaust nozzle compared with the annular ported exhaust nozzle has 20.5 percent greater area and due to a better coefficient of discharge will pass 24.6 percent more steam at a given back pressure. This means that more flue gas can be moved at a given back pressure. Also, either the same power may be developed on less back pressure or more power may be developed on the same back pressure.

The net area through the front end arrangement is 10.9 percent greater in locomotive 4010 than in locomotive 4007. It, therefore, offers less resistance and permits easier flow of gases and consequently less energy is needed to move the required amount of gases through the front end.

The larger ratio of stack to nozzle area of locomotive 4010 also helps increase the entrainment ratio of the front end.

Other front end dimensions although of lesser importance also serve to give the front end arrangement of locomotive 4010 a higher entrainment ratio than the front end arrangement of locomotive 4007.

Since the characteristics of engines and boilers of the two test locomotives are essentially the same, maximum output of the locomotives will be limited by the front end arrangements, and differences of maximum output will be attributable to differences in front end arrangements.

Locomotive 4007 was available for service 28 days in July, being out of service July 10 for nozzle change and July 23 and 24 for monthly inspection, with total mileage of 7181 miles for this month.

Locomotive 4007 has been released to pool service to obtain the reaction of enginemen and operating officers.

C-574.

J. Gogerty

MCH:hc

GENERAL PERFORMANCE

TABLE I

DATE 1948	Number of Cars Loads	Number of Cars Emptys	No. of Stops	TONS	GMTM	Duration of Test: TOTAL Hrs.	TOTAL Min.	DEAD Hrs.	DEAD Min.	RUNNING Hrs.	RUNNING Min.	Total Tank Water Pounds	Total Coal Fired Pounds	Per GMTM Pounds Water	Per GMTM Pounds Coal	Average Speed MPH
Westbound - Cheyenne to Sherman - 30.9 Miles																
LOCO 4007																
October 10	53	3	2	2431	75.12	2	15	0	8	2	7	147262	37552	1960.4	499.9	14.6
12	63	1	4	*2958	72.08	3	5	1	11	1	54	137175	35312	1903.1	489.9	16.3
13	54	17	2	**2832	87.51	3	43	1	15	2	28	191400	48640	2187.2	555.8	12.5
14	52	2	3	2616	80.83	3	11	1	3	2	8	166600	36632	2061.1	453.2	14.5
LOCO 4010																
October 23	46	12	1	2508	77.50	1	56	0	0	1	56	133850	27440	1727.1	354.1	16.0
24	54	4	1	2709	83.71	1	46	0	0	1	46	128250	30592	1532.1	365.5	17.5
25	57	9	3	2735	84.51	2	15	0	19	1	56	152525	32376	1804.8	383.1	16.0
26	50	14	1	2773	85.69	1	55	0	0	1	55	141200	34608	1647.8	403.9	16.1
Eastbound - Laramie to Sherman - 25.9 Miles																
LOCO 4007																
October 11	67	1	1	3571	92.49	1	4	0	0	1	4	94962	21040	1026.7	227.5	24.3
12	54	4	1	4114	106.55	1	16	0	0	1	16	95063	21296	892.2	199.9	20.4
13	62	4	1	3722	96.40	1	9	0	0	1	9	94581	17472	981.1	181.2	22.5
14	55	11	1	4376	113.34	1	19	0	0	1	19	104075	20416	918.3	180.1	19.7
LOCO 4010																
October 23	56	30	1	4054	105.00	1	12	0	0	1	12	103450	21768	985.2	207.3	21.6
24	67	1	1	3548	91.89	1	7	0	0	1	7	85600	18584	931.5	202.2	23.2
25	57	7	1	3532	91.48	1	3	0	0	1	3	79537	16464	869.4	180.0	24.7
26	75	12	1	4491	116.32	1	19	0	0	1	19	97069	28352	834.5	243.7	19.7

* Helper 5035 - Max. Tractive Force 70450 Lbs.

** 54 Loads, 17 E, 2965 Tons to Otto
54 Loads, 8 E, 2714 Tons Otto to Sherman
2832 Tons is average for trip Cheyenne to Sherman

F U E L - W A T E R - E V A P O R A T I O N

TABLE II

DATE 1948	Tank Water Total Pounds	Exhaust Steam Injector Condensate Pounds	Actual Evaporation Total Pounds	Coal Fired Total Pounds	Pounds Water Evap. Per Pound of Coal Fired Actual	Running Time Hours	Pounds of Coal Fired Per Hour Running Time	Millions of BTU's Absorbed by Evap. Heating Surface Per Hr. Running Time
			Westbound - Cheyenne to Sherman - 30.9 Miles					
LOCO 4007								
October 10	147262	9289	156551	37552	4.17	2.1167	17741	81.75
12	137175	8524	145699	35312	4.13	1.9000	18585	84.67
13	191400	15353	206753	48640	4.25	2.4667	19719	90.92
14	166600	11616	178216	36632	4.87	2.1333	17172	91.29
LOCO 4010								
October 23	133850	9930	147780	27440	5.39	1.9333	14193	83.56
24	128250	9786	138042	30592	4.51	1.7667	17316	84.78
25	152525	14210	166735	32376	5.15	1.9333	16746	92.70
26	141200	10680	151880	34608	4.39	1.9167	18056	86.36
			Eastbound - Laramie to Sherman - 25.9 Miles					
LOCO 4007								
October 11	94962	7151	102113	21040	4.85	1.0667	19724	104.57
12	95063	7755	102818	21296	4.83	1.2667	16812	87.63
13	94581	6773	101354	17472	5.80	1.1500	15193	96.34
14	104075	7672	111747	20416	5.47	1.3167	15505	92.63
LOCO 4010								
October 23	103450	9590	113040	21768	5.19	1.2000	18140	101.31
24	85600	7204	92804	18584	4.99	1.1167	16642	90.04
25	79537	6555	86092	16464	5.23	1.0500	15680	89.20
26	97069	7977	105046	28352	3.71	1.3167	21533	86.66

A V E R A G E   P R E S S U R E S   A N D   T E M P E R A T U R E S

TABLE III

DATE 1948	Pressure - Pounds Per Square Inch Gauge					Temperatures - Degrees Fahrenheit								
	Boiler	Valve Chamber	Exhaust Stand	Exhaust In Injector	Injector Live Steam Nozzle	Tank Water	Delivery Water	Steam To Cylinder Right	Steam To Cylinder Left	Exhaust Steam Right Back	Exhaust Steam Left Back	Exhaust Steam Front Engine	Smoke Box Gases Right	Smoke Box Gases Left
Westbound - Cheyenne to Sherman - 30.9 Miles														
LOCO 4007														
October 10	286.2	271.9	12.9	10.1	271.3	57.4	227.6	664.2	654.2	314.3	331.4	322.8	651.9	665.4
12	290.6	273.9	17.5	15.4	275.8	59.3	240.5	706.2	679.4	338.9	352.3	354.0	679.3	678.4
13	292.2	277.0	17.0	15.2	277.1	59.0	234.8	704.8	683.4	342.5	361.1	364.5	675.6	677.9
14	288.9	273.0	17.8	13.6	272.7	63.0	227.7	677.2	679.4	331.8	350.4	359.8	672.1	683.9
LOCO 4010														
October 23	298.4	286.8	13.1	8.7	276.0	56.6	235.2	725.6	697.4	366.3	353.7	363.2	731.9	735.1
24	301.7	289.3	13.6	9.9	278.9	63.0	240.1	733.4	704.1	364.4	348.1	364.5	735.6	738.8
25	302.1	288.9	12.9	10.1	280.0	55.3	252.1	740.0	700.2	364.9	356.1	362.2	724.6	707.8
26	300.7	287.3	12.9	9.0	277.8	58.6	236.1	723.6	701.3	363.9	349.4	367.0	724.5	735.1
Eastbound - Laramie To Sherman - 25.9 Miles														
LOCO 4007														
October 11	298.2	270.9	16.2	13.9	281.1	58.0	230.3	666.1	661.8	309.6	323.5	320.7	658.6	672.1
12	289.3	272.2	17.8	15.8	273.8	63.2	231.8	693.2	677.2	331.8	353.5	353.5	665.8	683.5
13	298.2	284.2	16.2	13.1	281.2	61.1	225.5	684.0	672.3	304.5	324.8	327.2	665.5	678.4
14	298.2	283.2	16.2	13.5	281.0	60.0	224.4	693.7	675.8	330.3	343.2	348.5	683.1	676.9
LOCO 4010														
October 23	294.9	281.4	15.6	11.3	272.2	53.8	240.3	744.5	715.2	384.1	376.8	382.4	737.0	754.0
24	296.0	283.9	12.3	8.7	274.5	56.9	243.4	726.6	687.2	342.4	326.1	335.5	726.9	713.9
25	299.3	288.7	12.9	8.9	276.3	53.7	244.0	749.0	711.1	350.2	339.9	340.4	734.1	736.2
26	299.2	287.8	12.6	9.6	277.2	55.4	238.6	731.9	706.8	358.5	347.3	358.2	719.9	740.8

EVAPORATION AND TEMPERATURE RISE DUE TO EXHAUST STEAM CONDENSED BY EXHAUST STEAM INJECTOR

DATE 1948	Running Time Hours	Pounds Of Tank Water Fed To Boiler: Exhaust Steam Operation	Pounds Of Tank Water Fed To Boiler: Live Steam Operation	Total Tank Water	Condensate Return Pounds	Total Pounds Water Evaporated By Boiler Actual	Temp. Rise Due To Exhaust Steam Degrees F.	Percent Return	Millions Of BTUs Absorbed By Evaporative Heating Surface
Westbound - Cheyenne To Sherman - 30.9 Miles									
LOCO 4007									
October 10	2.1167	130394	16868	147262	9289	156551	63.61	5.93	173.04
12	1.9000	104727	32448	137175	8524	145699	63.10	5.85	160.87
13	2.4667	174402	16998	191400	15353	206753	82.78	7.43	224.26
14	2.1333	148294	18306	166600	11616	178216	71.30	6.52	194.75
LOCO 4010									
October 23	1.9333	125379	8471	133850	9930	147780	76.95	6.91	161.55
24	1.7667	125436	2814	128250	9786	138042	78.75	7.09	149.79
25	1.9333	142670	9855	152525	14210	166735	96.57	8.52	179.22
26	1.9167	138849	2351	141200	10680	151880	78.34	7.03	165.53
Eastbound - Laramie To Sherman - 25.9 Miles									
LOCO 4007									
October 11	1.0667	87547	7415	94962	7151	102113	76.29	7.00	111.55
12	1.2667	91818	3245	95063	7755	102818	83.65	7.54	111.00
13	1.1500	90241	4340	94581	6773	101354	72.54	6.68	110.79
14	1.3167	99966	4109	104075	7672	111747	75.60	6.87	121.97
LOCO 4010									
October 23	1.2000	98622	4828	103450	9590	113040	97.33	8.48	121.57
24	1.1167	81868	3932	85600	7204	92804	86.29	7.76	100.54
25	1.0500	71114	8423	79537	6555	86092	85.10	7.61	93.66
26	1.3167	96359	710	97069	7977	105046	85.07	7.59	114.10

ELESCO EXHAUST STEAM INJECTOR PERFORMANCE

TABLE V

DATE 1948	Hours Injector Operates On Exhaust Steam	Hours Injector Operates On Live Steam	Tank Water Delivered To Boiler Exhaust Steam Operation	Tank Water Delivered To Boiler Live Steam Operation	Tank Water Delivered To Boiler Total	Running Time Hours	Temp. Degrees F. Delivered To Boiler	Temp. Degrees F. Tank Water	Pounds Live Steam Used By Injector Exh. Steam Oper.	Pounds Live Steam Used By Pump Total	Pounds Exhaust Steam Condensed	Total Lbs. Water Fed To Boiler	Cond. Return % Total Water To Boiler	Net Temp. Rise Due To Exh. Steam Condensed	% Cond. Return Exh. Steam Operation	Temp. Rise Due To Exh. Steam Condensed On Exh. Operation
Westbound - Cheyenne To Sherman - 30.9 Miles																
LOCO 4007																
October 10	2.0117	0.2667	130394	16868	147262	2.1167	227.6	57.4	12855	842	9289	156551	5.93	63.61	6.65	72.12
12	1.6122	0.4917	104727	32448	137175	1.9000	240.5	59.3	10573	779	8524	145699	5.85	63.10	7.53	83.06
13	2.3128	0.2355	174402	16998	191400	2.4667	234.8	59.0	15234	981	15353	206753	7.43	82.78	8.09	90.75
14	1.9536	0.3528	148294	18306	166600	2.1333	227.7	63.0	12675	879	11616	178216	6.52	71.30	7.26	80.40
LOCO 4010																
October 23	1.6411	0.1436	125379	8471	133850	1.9333	235.2	56.6	12413	687	9930	147780	6.91	76.95	7.34	82.25
24	1.6367	0.0353	125436	2814	128250	1.7667	240.1	63.0	12501	648	9786	138042	7.09	78.75	7.24	80.50
25	1.8583	0.1164	142670	9855	152525	1.9333	252.1	55.3	14248	766	14210	166735	8.52	96.57	9.06	102.97
26	1.8325	0.0314	138849	2351	141200	1.9167	236.1	58.6	13945	719	10680	151880	7.03	78.34	7.14	79.66
Eastbound - Laramie to Sherman - 25.9 Miles																
LOCO 4007																
October 11	1.1933	0.1411	87547	7415	94962	1.0667	230.3	58.0	7968	507	7151	102113	7.00	76.29	7.55	82.93
12	1.1792	0.0425	91818	3245	95063	1.2667	231.8	63.2	7680	475	7755	102818	7.54	83.65	7.79	86.57
13	1.2011	0.0717	90241	4340	94581	1.1500	225.5	61.1	8022	489	6773	101354	6.68	72.54	6.98	76.13
14	1.2914	0.0664	99966	4109	104075	1.3167	224.4	60.0	8619	526	7672	111747	6.87	75.60	7.13	78.80
LOCO 4010																
October 23	1.1695	0.0608	98622	4828	103450	1.2000	240.3	53.8	8733	489	9590	113040	8.48	97.33	8.86	101.93
24	1.0947	0.0539	81868	3932	85600	1.1167	243.4	56.9	8238	436	7204	92804	7.76	86.29	8.09	90.18
25	0.9297	0.1094	71114	8423	79537	1.0500	244.0	53.7	7040	402	6555	86092	7.61	85.10	8.44	94.96
26	1.2797	0.0103	96359	710	97069	1.3167	238.6	55.4	9719	497	7977	105046	7.59	85.07	7.65	85.69

FUEL SAVED BY OPERATION OF ELESCO EXHAUST STEAM INJECTOR

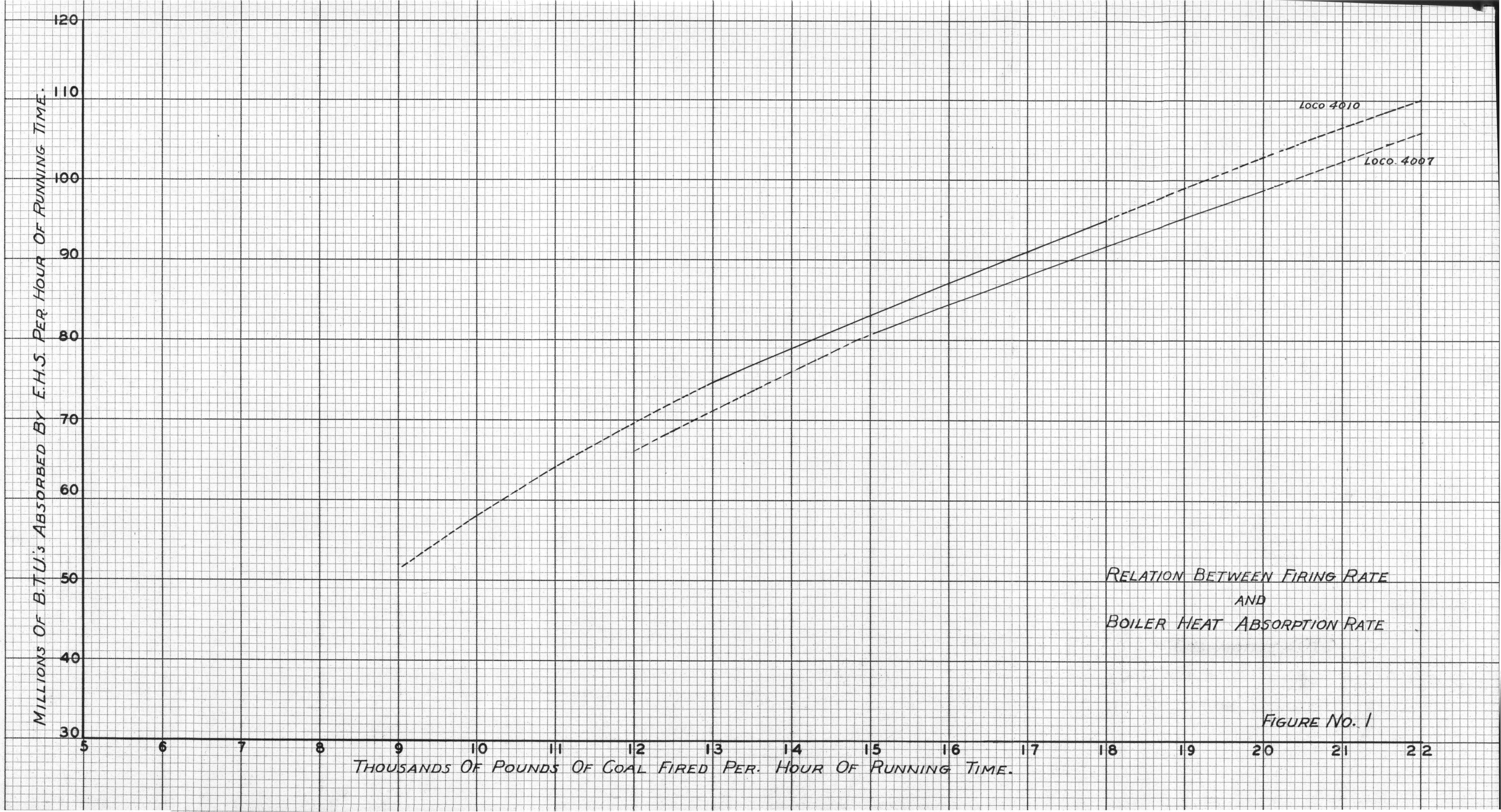
TABLE VI

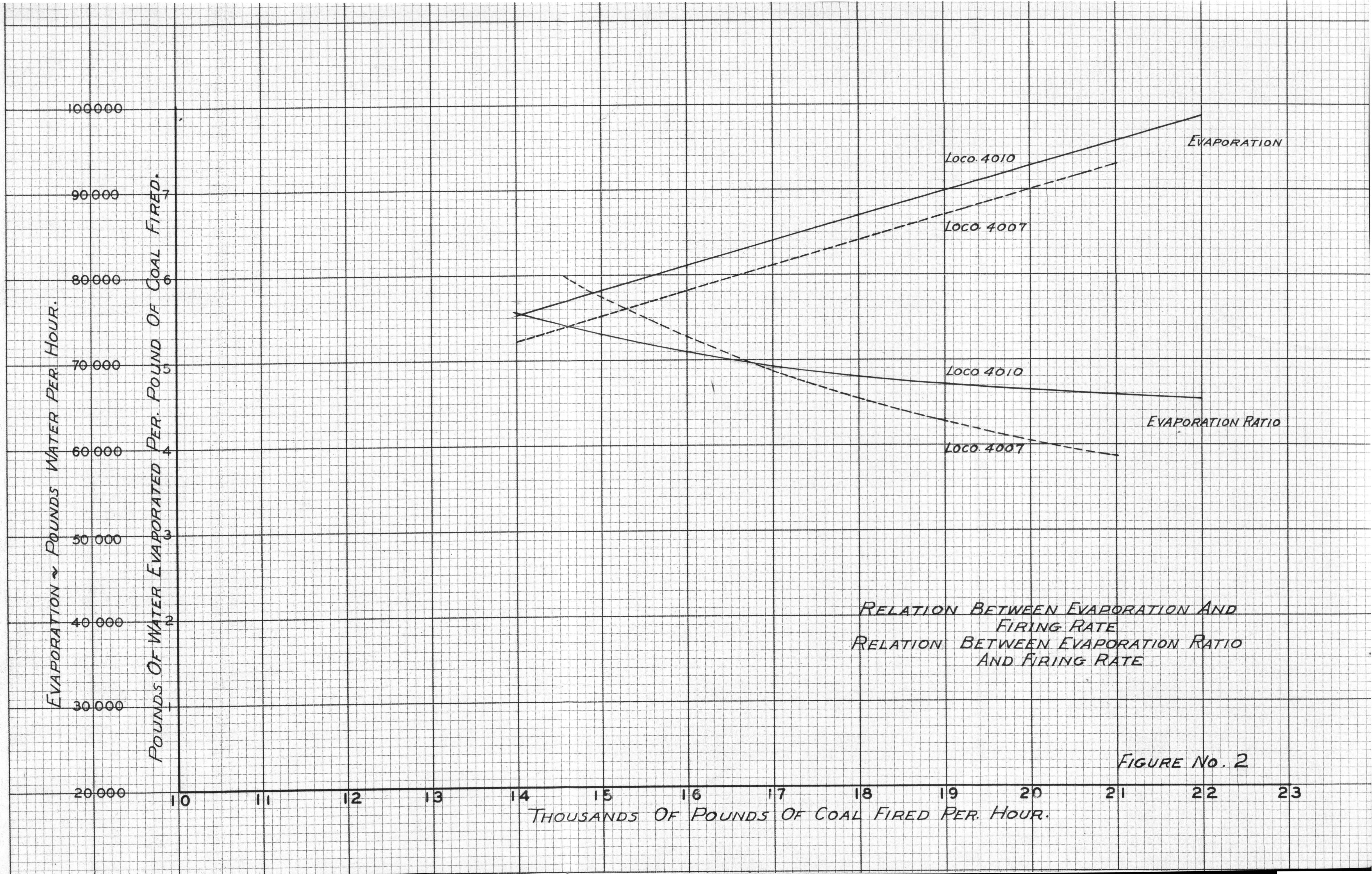
DATE 1948	Boiler Press. Pounds Per Sq. Inch Gauge	Tank Water Temp. Degrees F.	Net Temp. Rise Due To Exhaust Steam Condensed	Water Actually Evaporated By Boiler Total Pounds	Running Time Hours	Millions Of BTU's Absorbed By Evap. Heating Surface Per Hour: Actual	Millions Of BTU's Absorbed By Evap. Heating Surface Per Hour: If Fed By Live Steam Injector	Coal Per Hour From Firing Rate Heat Absorption Curve: Exhaust Steam Operation	Coal Per Hour From Firing Rate Heat Absorption Curve: If Fed By Live Steam Injector	Coal Rate Difference Pounds Per Hour	Pounds Coal Saved Per Trip By Exh. Steam Injector
Westbound - Cheyenne To Sherman - 30.9 Miles											
LOCO 4007											
October 10	286.2	57.4	63.61	156551	2.1167	81.75	86.45	15318	16613	1295	2741
12	290.6	59.3	63.10	145699	1.9000	84.67	89.51	16168	17458	1290	2451
13	292.2	59.0	82.78	206753	2.4667	90.92	97.86	17885	19817	1932	4766
14	288.9	63.0	71.30	178216	2.1333	91.29	97.25	18000	19643	1643	3505
LOCO 4010											
October 23	298.4	56.6	76.95	147780	1.9333	83.56	89.45	15140	16583	1443	2790
24	301.7	63.0	78.75	138042	1.7667	84.78	90.93	15445	16598	1153	2037
25	302.1	55.3	96.57	166735	1.9333	92.70	101.03	17375	19603	2228	4307
26	300.7	58.6	78.34	151880	1.9167	86.36	92.57	15840	17343	1503	2881
Eastbound - Laramie To Sherman - 25.9 Miles											
LOCO 4007											
October 11	298.2	58.0	76.29	102113	1.0667	104.57	111.88	21667	24000	2333	2488
12	289.3	63.2	83.65	102818	1.2667	87.63	94.43	16953	18842	1889	2393
13	298.2	61.1	72.54	101354	1.1500	96.34	102.73	19383	21147	1764	2029
14	298.2	60.0	75.60	111747	1.3167	92.63	99.02	18342	20141	1799	2369
LOCO 4010											
October 23	294.9	53.8	97.33	113040	1.2000	101.31	110.48	19528	22141	2613	3136
24	296.0	56.9	86.29	92804	1.1167	90.04	97.21	16724	18503	1779	1987
25	299.3	53.7	85.10	86092	1.0500	89.20	96.18	16524	18245	1721	1807
26	299.2	55.4	85.07	105046	1.3167	86.66	93.45	15915	17563	1648	2170

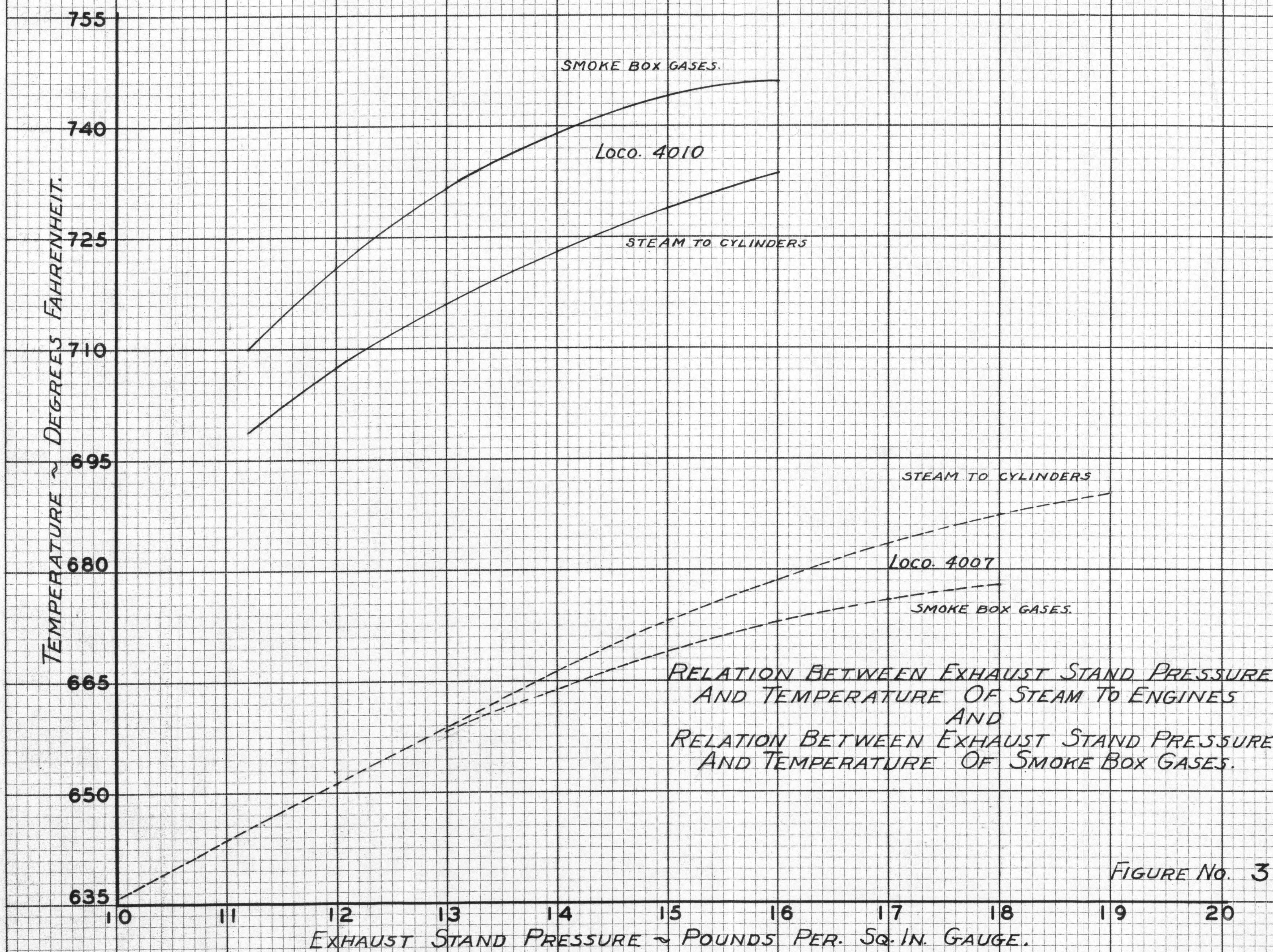
AVERAGE WATER RATES AND INDICATED HORSEPOWER

TABLE VII

DATE 1948	Exhaust Stand Press. PSI Gauge P_1	Exhaust Stand Temp. Degrees F T_1	Valve Chamber Press. PSI Gauge	Valve Chamber Temp. Degrees F	Exhaust Stand Entropy	Exhaust Stand Specific Volume V_1	Exhaust Stand Enthalpy H_1	After Adiabatic Expan. From P_1 to P_2: Press. P_2 PSI Absolute	After Adiabatic Expan.: Specific Volume V_2	After Adiabatic Expan.: Enthalpy H_2	Jet Velocity Ft. Per Sec. V_2	Pounds Steam Per Hour Through Exhaust Nozzle W_y	Pounds Steam Per Hour To Engines W_e	Enthalpy Steam To Engines H_p	Velocity Of Steam In Exhaust Pipes Ft/Sec. V_1	Correction For Rad. & Velocity of Steam in Exh. Pipes BTU per Lb.	Lbs. Steam per Ind. Horse-power Hour	Indicated Horse-power
Westbound - Cheyenne to Sherman - 30.9 Miles																		
LOCO 4007																		
October 10	12.9	327.1	271.9	659.2	1.7674	17.864	1202.8	15.0	27.03	1159.2	1481.8	60034	64567	1346.6	104.9	1.9857	17.95	3597
12	17.5	348.4	273.9	692.8	1.7614	15.572	1212.2	17.7	23.54	1167.6	1498.3	67578	73411	1364.6	102.9	1.7647	16.89	4346
13	17.0	356.0	277.0	694.1	1.7677	15.987	1216.0	17.4	24.18	1170.7	1510.0	66139	72310	1359.7	103.4	1.7903	17.93	4033
14	17.8	347.3	273.0	678.3	1.7596	15.395	1211.6	17.9	23.27	1167.6	1488.1	67997	73639	1356.8	102.4	1.7578	17.75	4149
LOCO 4010																		
October 23	13.1	361.1	268.8	711.5	1.7866	18.529	1219.0	15.1	28.05	1173.2	1520.2	74101	80323	1374.1	134.4	1.7803	16.60	4839
24	13.6	359.3	289.3	718.8	1.7834	18.139	1218.1	15.4	27.47	1172.5	1516.9	75503	81750	1377.9	134.0	1.7536	16.10	5078
25	12.9	361.1	288.9	720.1	1.7875	18.674	1219.0	15.0	28.25	1173.4	1516.9	73418	81171	1378.8	134.2	1.7646	16.10	5042
26	12.9	360.1	287.3	712.5	1.7870	18.650	1218.5	15.0	28.22	1173.0	1515.1	73404	79386	1374.6	134.0	1.7951	16.49	4814
Eastbound - Laramie To Sherman-25.9 Miles																		
LOCO 4007																		
October 11	16.2	317.9	270.9	664.0	1.7478	15.622	1197.8	16.9	23.68	1154.6	1474.6	65691	71377	1349.3	100.4	1.7988	17.00	4199
12	17.8	346.3	272.2	685.2	1.7590	15.374	1211.1	17.9	23.21	1166.7	1495.0	68489	74622	1360.6	103.0	1.7399	17.22	4333
13	16.2	318.8	284.2	678.2	1.7483	15.641	1198.2	16.9	23.70	1154.9	1476.2	65706	70932	1350.7	100.5	1.8093	16.89	4200
14	16.2	340.7	283.2	684.8	1.7613	16.108	1208.7	16.9	24.37	1164.0	1499.9	64926	70210	1359.7	102.3	1.8330	17.06	4115
LOCO 4010																		
October 23	15.6	381.1	281.4	729.9	1.7876	17.324	1228.1	16.6	26.19	1181.4	1535.0	80139	88397	1384.2	135.9	1.6590	16.48	5364
24	12.3	334.7	283.9	706.9	1.7747	18.483	1206.6	14.7	27.91	1162.6	1490.1	72999	79810	1371.7	132.0	1.7770	15.58	5123
25	12.9	343.5	288.7	730.1	1.7772	18.256	1210.7	15.0	27.62	1166.0	1501.9	74350	81615	1384.1	132.8	1.7495	14.83	5503
26	12.6	354.7	287.8	719.4	1.7851	18.746	1216.1	14.8	28.41	1170.6	1515.1	72918	79321	1378.4	133.8	1.7950	15.86	5001


Millions Of B.T.U.'s Absorbed By E.H.S. Per Hour Of Running Time.
120
110
100
90
80
70
60
50
40
30
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
Thousands Of Pounds Of Coal Fired Per. Hour Of Running Time.
Loco 4010
Loco. 4007
Relation Between Firing Rate
and
Boiler Heat Absorption Rate
Figure No. 1


EVAPORATION ~ POUNDS WATER PER. HOUR.
POUNDS OF WATER EVAPORATED PER. POUND OF COAL FIRED.
100000
90000
80000
70000
60000
50000
40000
30000
20000
7
6
5
4
3
2
1
10
11
12
13
14
15
16
17
18
19
20
21
22
23
THOUSANDS OF POUNDS OF COAL FIRED PER. HOUR.
EVAPORATION
LOCO. 4010
LOCO. 4007
LOCO 4010
EVAPORATION RATIO
LOCO. 4007
RELATION BETWEEN EVAPORATION AND FIRING RATE
RELATION BETWEEN EVAPORATION RATIO AND FIRING RATE
FIGURE NO. 2



RELATION BETWEEN EXHAUST STAND PRESSURE AND TEMPERATURE OF STEAM TO ENGINES AND RELATION BETWEEN EXHAUST STAND PRESSURE AND TEMPERATURE OF SMOKE BOX GASES.

FIGURE NO. 3

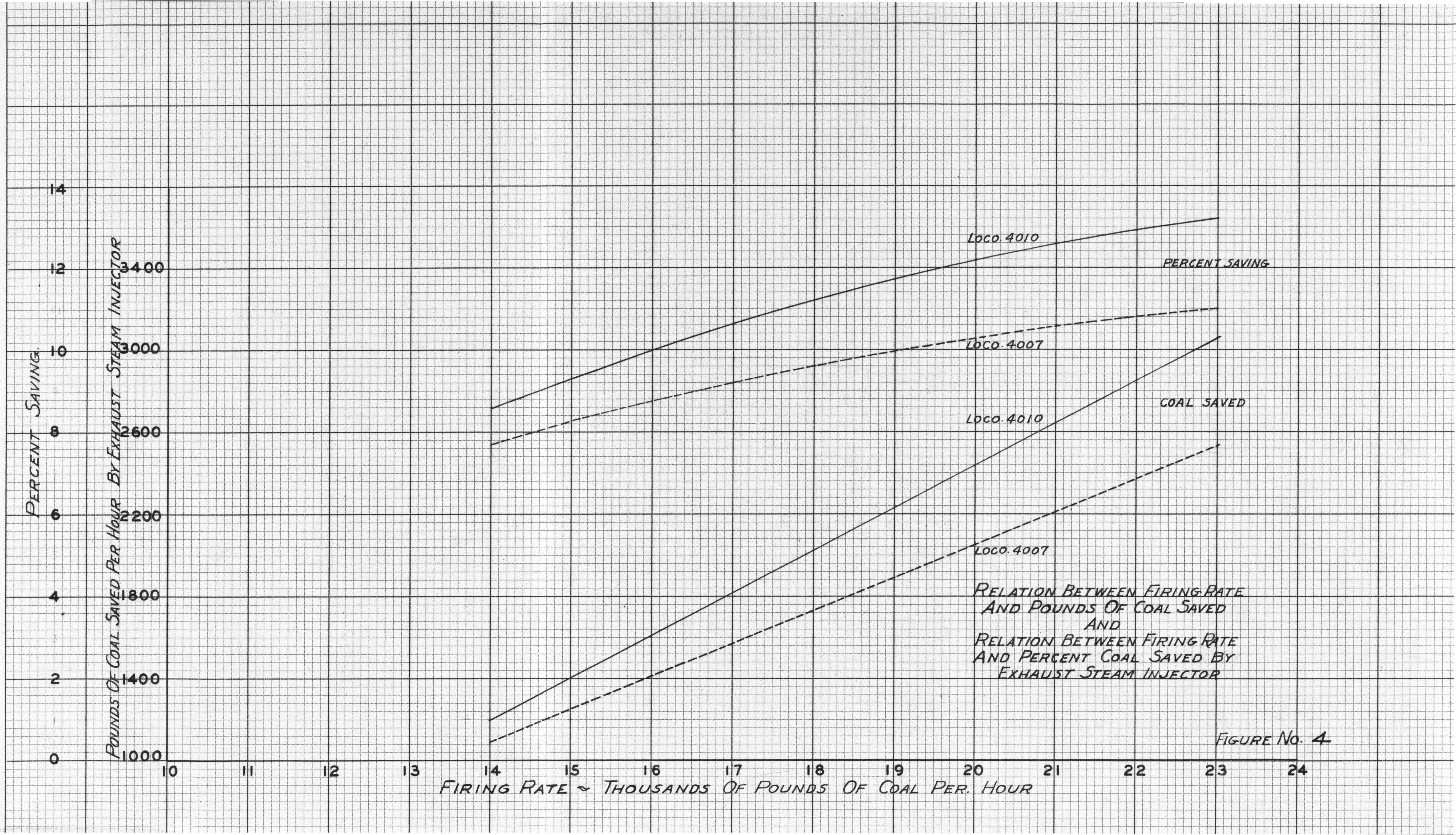
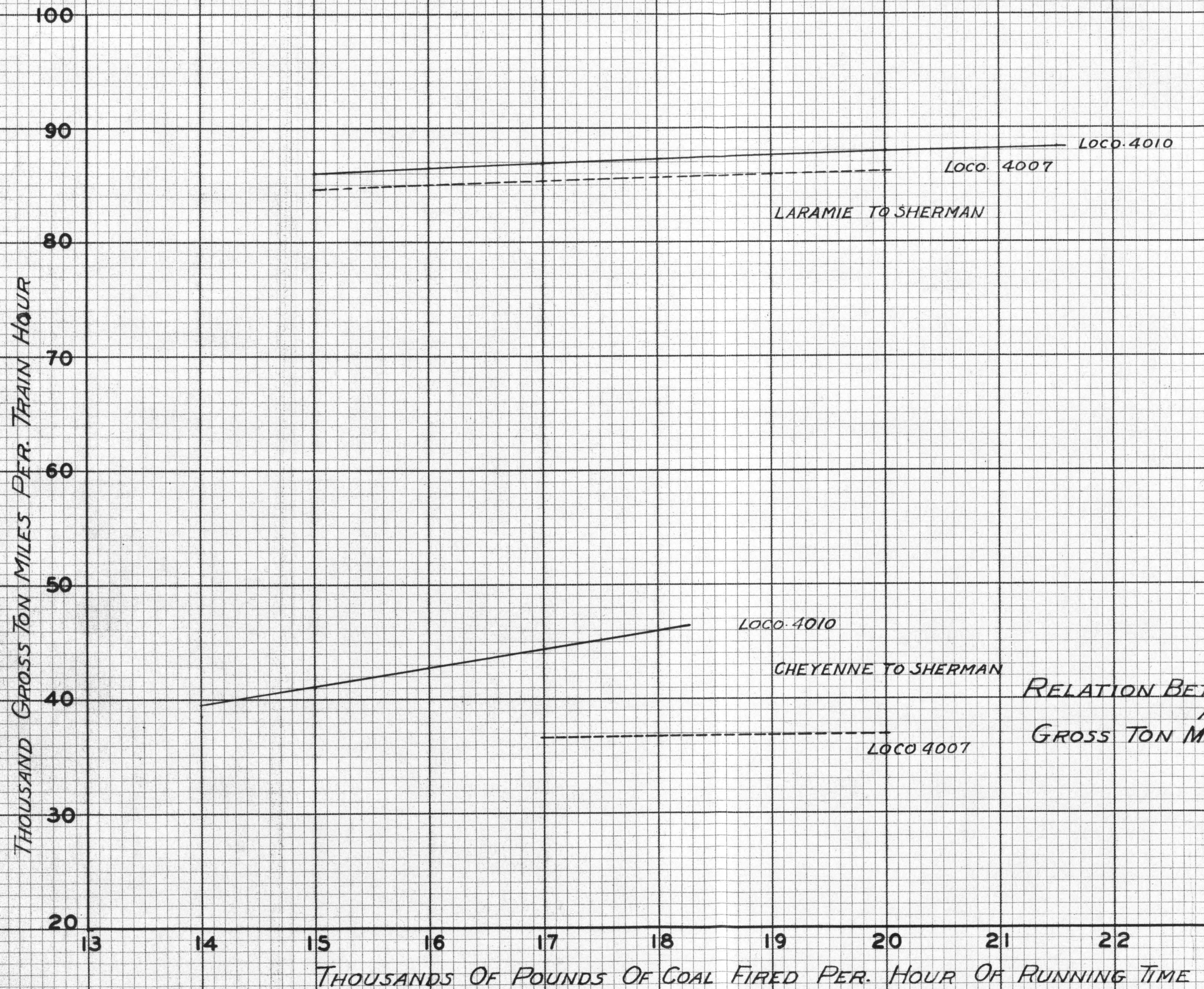
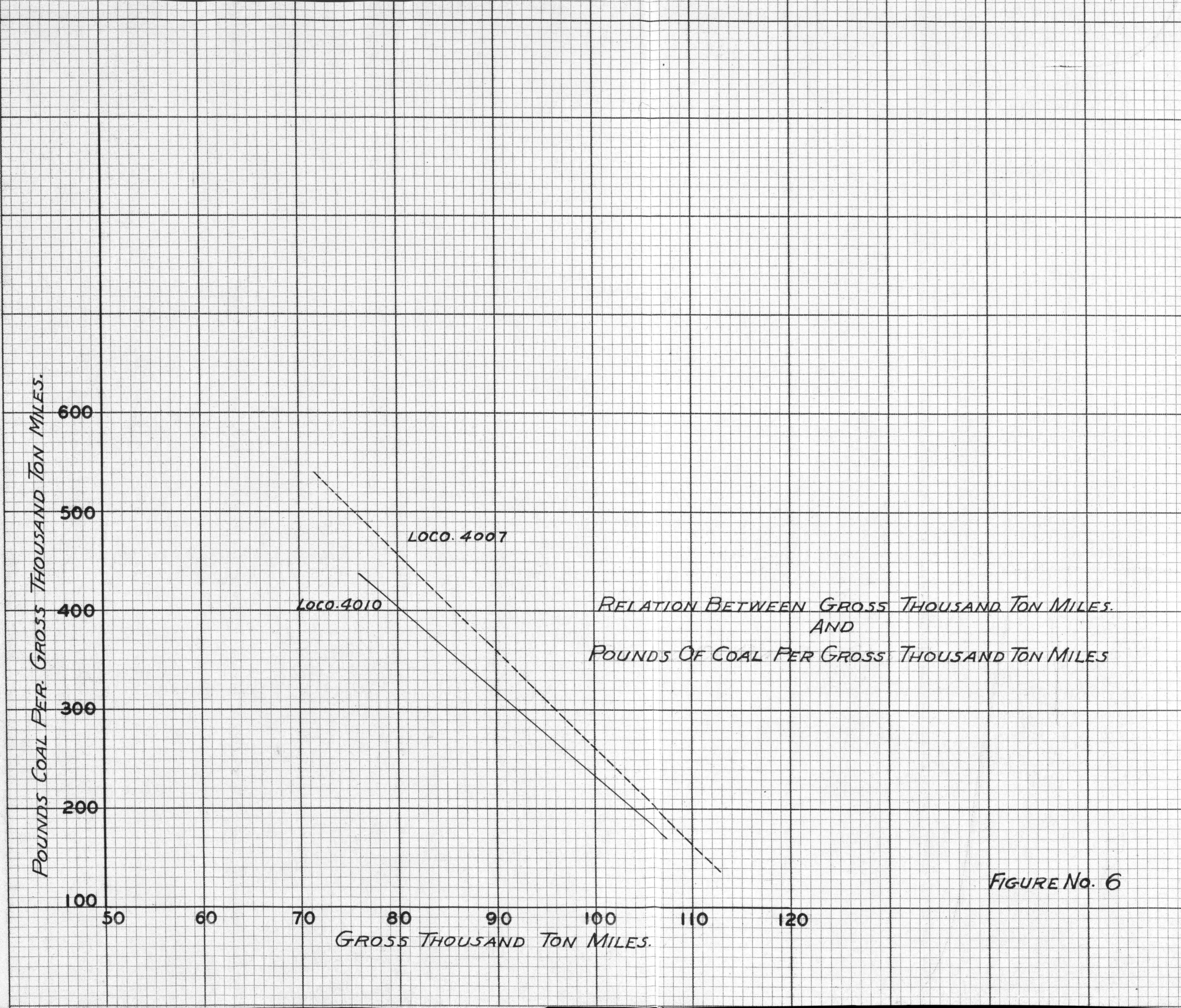

Percent Saving.
Pounds Of Coal Saved Per Hour By Exhaust Steam Injector
0
2
4
6
8
10
12
14
1000
1400
1800
2200
2600
3000
3400
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Firing Rate ~ Thousands Of Pounds Of Coal Per. Hour
Loco. 4010
Percent Saving
Loco. 4007
Coal Saved
Loco. 4010
Loco. 4007
Relation Between Firing Rate
And Pounds Of Coal Saved
And
Relation Between Firing Rate
And Percent Coal Saved By
Exhaust Steam Injector

Figure No. 4



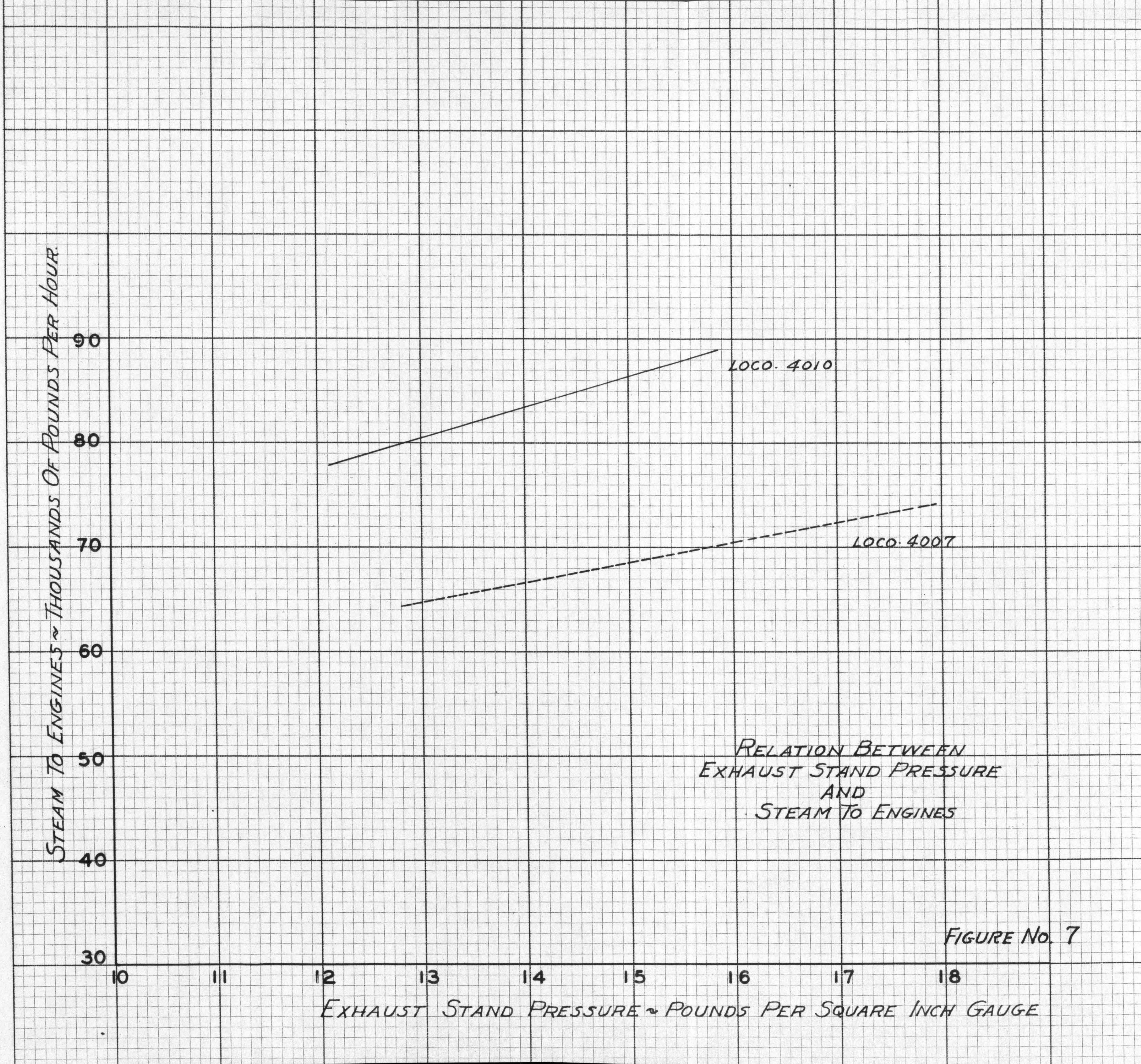
Relation Between Firing Rate
And
Gross Ton Miles Per. Train Hour

Figure No 5



POUNDS COAL PER. GROSS THOUSAND TON MILES.
600
500
400
300
200
100
50
60
70
80
90
100
110
120
GROSS THOUSAND TON MILES.
LOCO. 4007
LOCO. 4010
RELATION BETWEEN GROSS THOUSAND TON MILES.
AND
POUNDS OF COAL PER GROSS THOUSAND TON MILES

FIGURE NO. 6



STEAM TO ENGINES ~ THOUSANDS OF POUNDS PER HOUR.
90
80
70
60
50
40
30
10
11
12
13
14
15
16
17
18
EXHAUST STAND PRESSURE ~ POUNDS PER SQUARE INCH GAUGE
LOCO. 4010
LOCO. 4007
RELATION BETWEEN
EXHAUST STAND PRESSURE
AND
STEAM TO ENGINES

FIGURE NO. 7

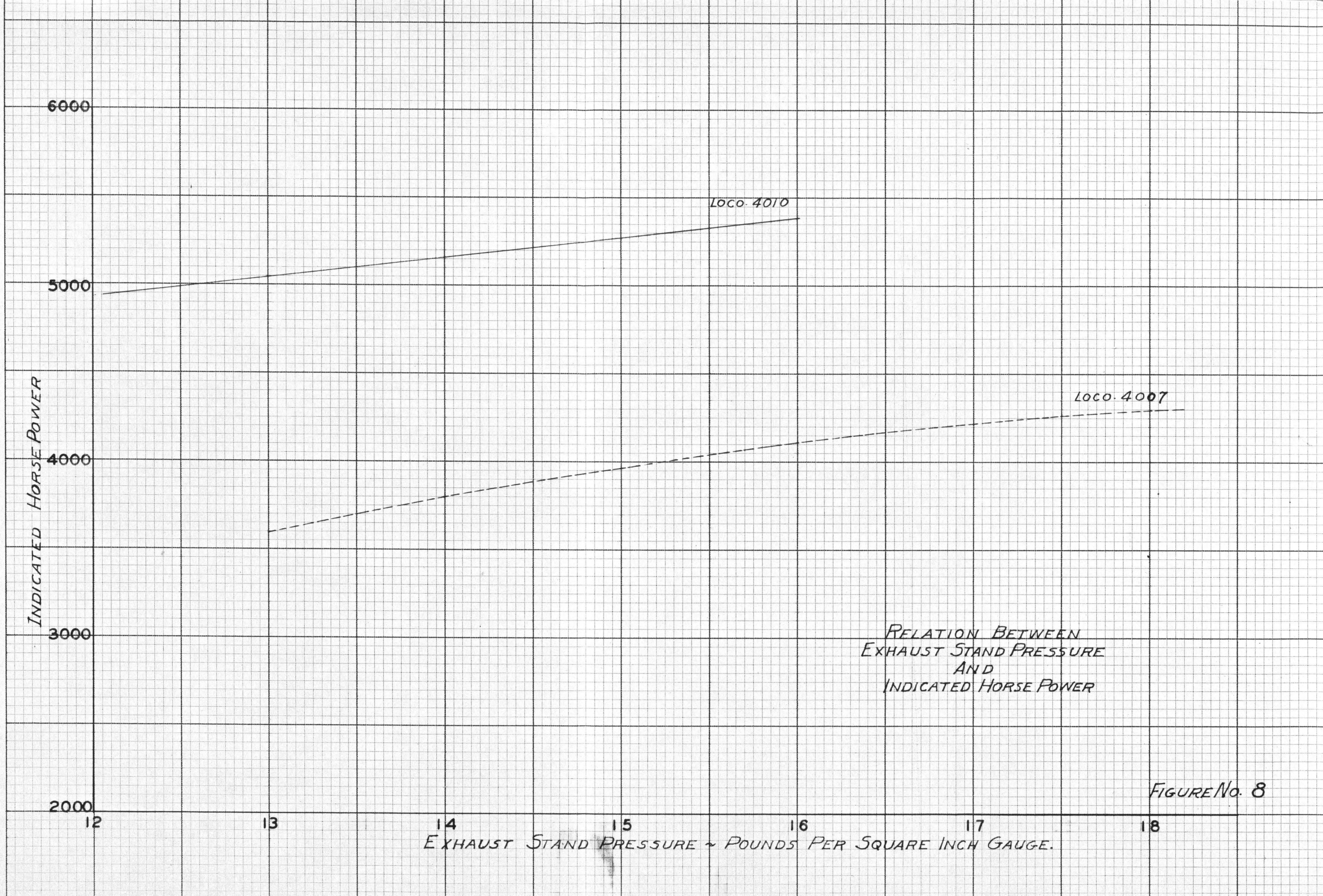
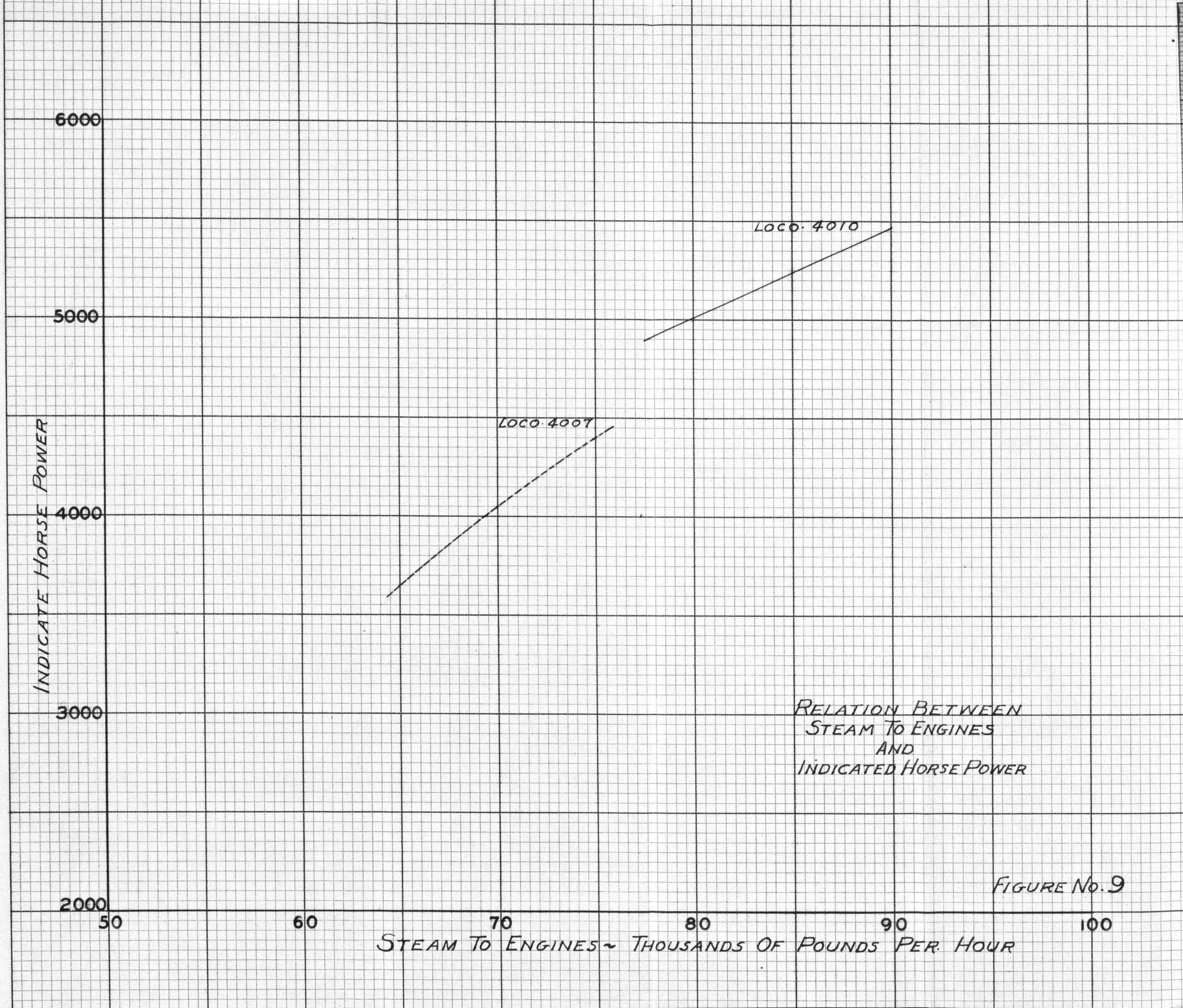

Loco. 4010
Loco. 4007
6000
5000
4000
3000
2000
Indicated Horse Power
12
13
14
15
16
17
18
Exhaust Stand Pressure ~ Pounds Per Square Inch Gauge.
Relation Between
Exhaust Stand Pressure
And
Indicated Horse Power

Figure No. 8


6000
5000
4000
3000
2000
50
60
70
80
90
100
INDICATE HORSE POWER
STEAM TO ENGINES ~ THOUSANDS OF POUNDS PER HOUR
LOCO. 4010
LOCO. 4007
RELATION BETWEEN
STEAM TO ENGINES
AND
INDICATED HORSE POWER
FIGURE No. 9

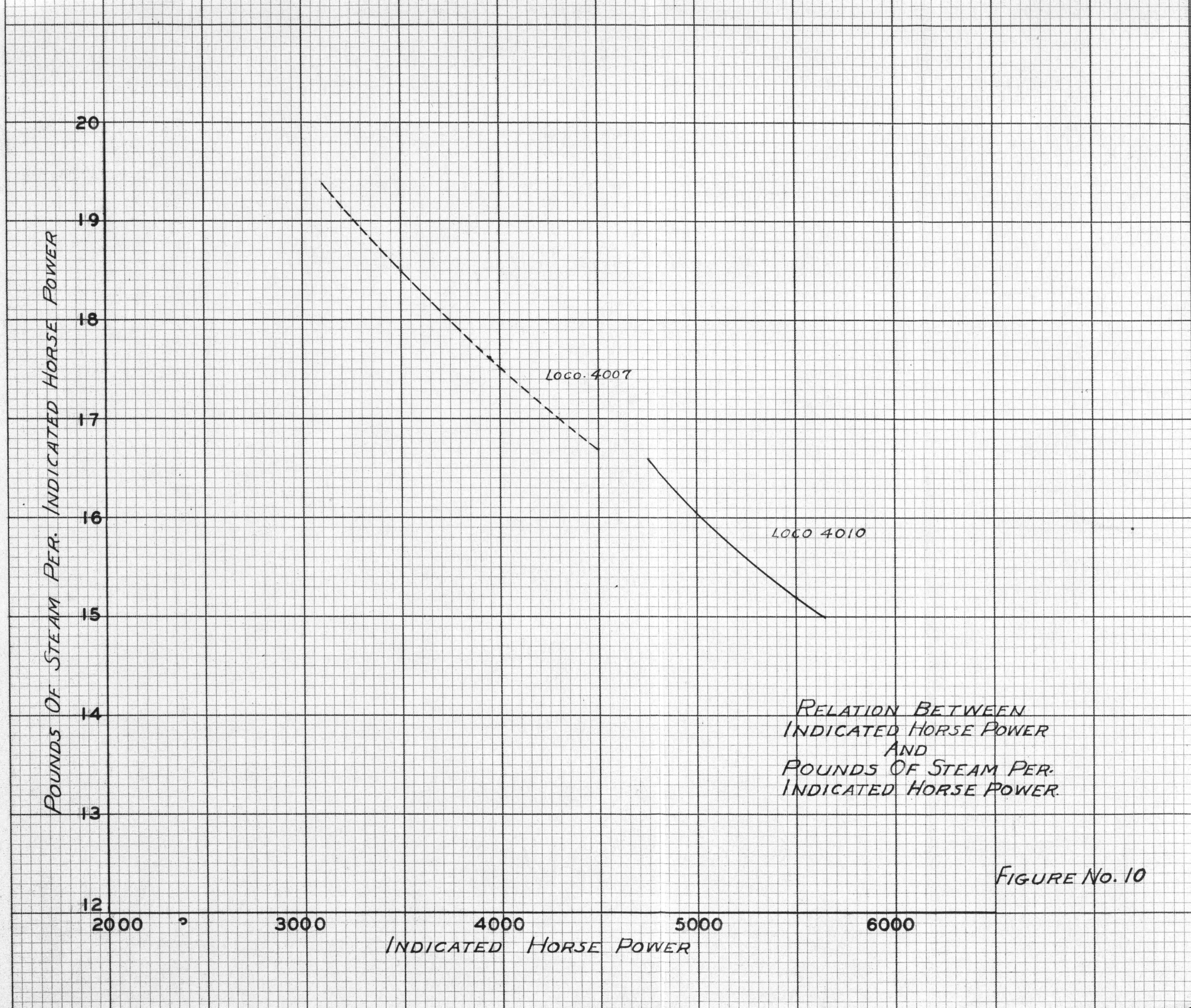
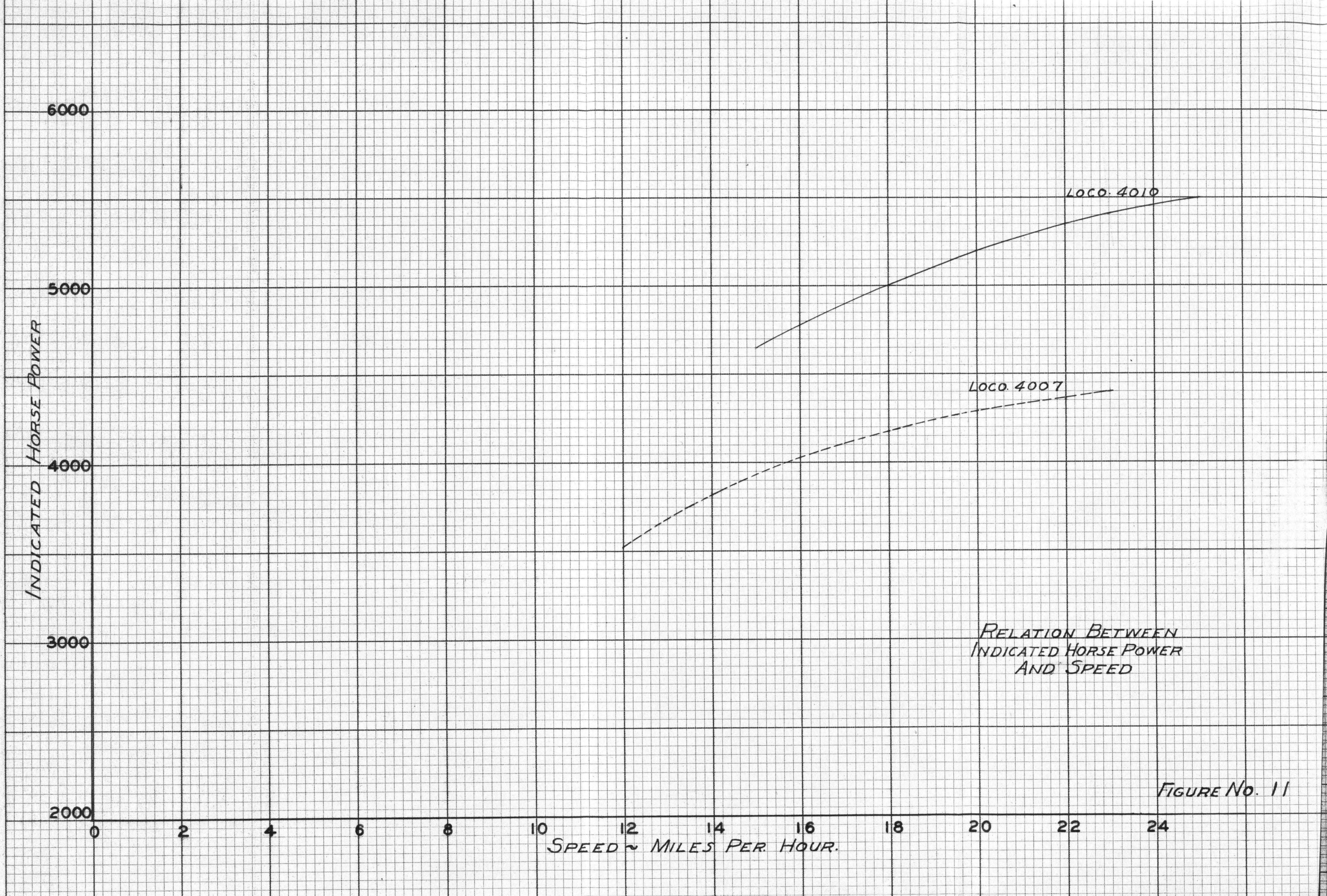
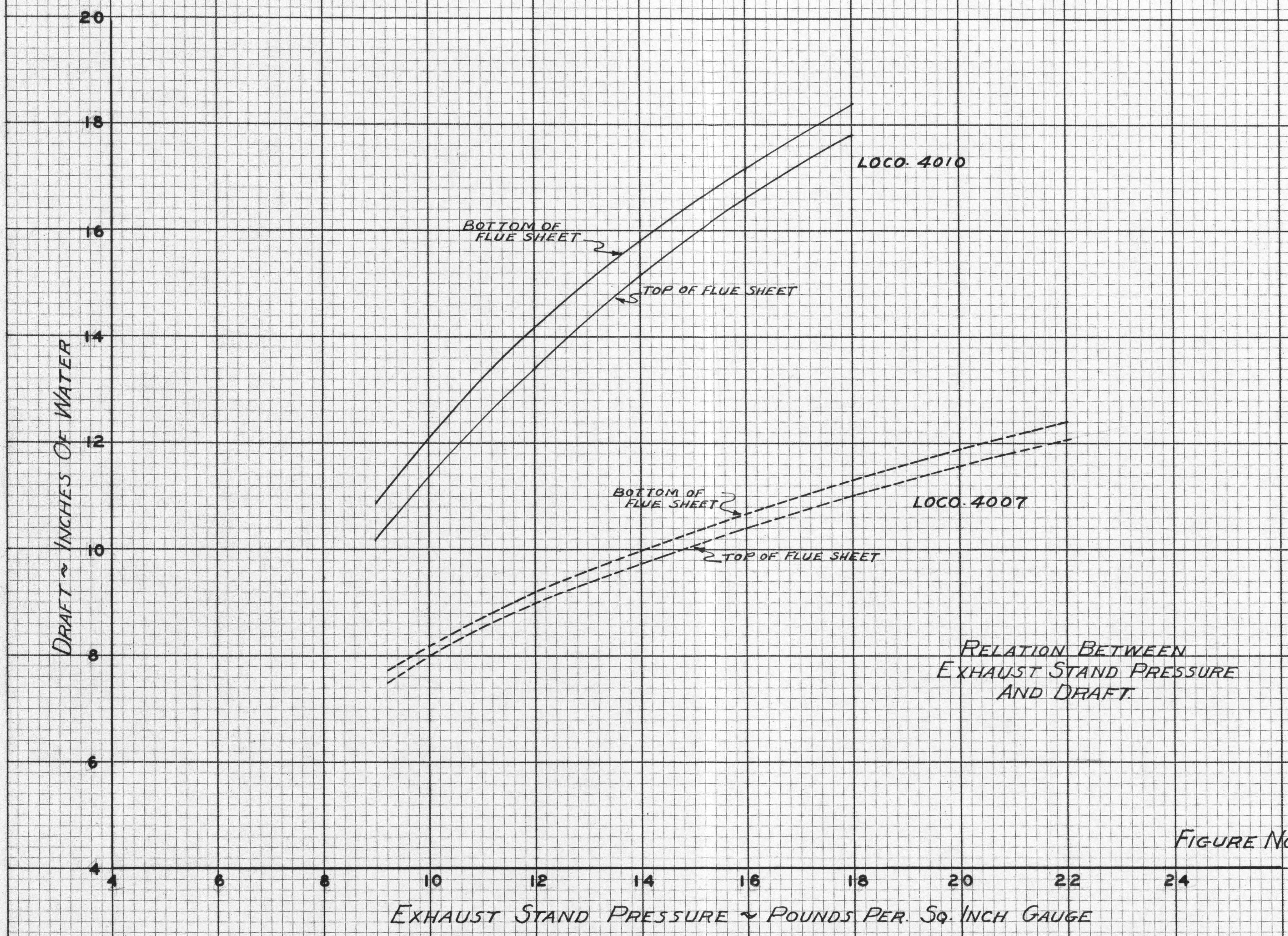

Pounds Of Steam Per. Indicated Horse Power
20
19
18
17
16
15
14
13
12
2000
3000
4000
5000
6000
Indicated Horse Power
Loco. 4007
Loco 4010
Relation Between
Indicated Horse Power
And
Pounds Of Steam Per.
Indicated Horse Power.

Figure No. 10


LOCO. 4010
LOCO. 4007
INDICATED HORSE POWER
6000
5000
4000
3000
2000
0
2
4
6
8
10
12
14
16
18
20
22
24
SPEED ~ MILES PER HOUR.
RELATION BETWEEN
INDICATED HORSE POWER
AND SPEED
FIGURE NO. 11



20
18
16
14
12
10
8
6
4
4
6
8
10
12
14
16
18
20
22
24
DRAFT ~ INCHES OF WATER
EXHAUST STAND PRESSURE ~ POUNDS PER. SQ. INCH GAUGE
LOCO. 4010
BOTTOM OF FLUE SHEET
TOP OF FLUE SHEET
LOCO. 4007
BOTTOM OF FLUE SHEET
TOP OF FLUE SHEET
RELATION BETWEEN EXHAUST STAND PRESSURE AND DRAFT.

FIGURE NO 12