NATIONAL BUREAU OF STANDARDS REPORT

4309

EFFECT OF CHANGES OF ENGINE SPEED ON THE CAPACITY OF THE 1/3-TON CARRIER REFRIGERATING UNIT, MODEL D731-9644

by

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Report to
Mechanical Engineering Division
Headquarters, Quartermaster Research & Development Command
Natick, Mass.

NBS

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Abstract

A study was made of the effect of speed change, ambient temperature, and refrigerator temperature on the net refrigerating capacity of a plug-type refrigerating unit, Model D731-9644, manufactured by Carrier Corporation of Syracuse, New York. The test specimen, of nominal 1/3-ton capacity, was constructed with the compressor and condenser fan coupled directly to the gasoline engine whereas the evaporator fan was driven at constant speed by a direct current electric motor powered by a generator built integrally with the engine. The results showed that at constant speed the net refrigerating capacity increased linearly with increase in refrigerator temperature when the ambient temperature was constant, and decreased linearly with increase in ambient temperature when the refrigerator temperature was constant. A maximum net refrigerating capacity of 4160 Btu/hr was observed at an engine speed of 2700 rpm. The unit attained about 93 percent of the nominal 1/3-ton rating at the design engine speed although the engine speed varied in excess of 10 percent from test to test under control of the governor. At speeds near the design speed the capacity of the unit varied approximately in direct proportion to the speed.

1. INTRODUCTION

At the request of the Office of the Quartermaster General studies were made of a 1/3-ton gasoline-engine driven refrigerating unit of the plug type, Model D731-9644, manufactured by Carrier Corporation, Syracuse, New York, to determine the effect of changes of ambient temperature, refrigerator temperature, and engine speed on the net refrigerating capacity.

Tests were made in the range of ambient temperature from 70°F to 125°F, and in the range of refrigerator temperature from -22°F to 35°F at design engine speed, and tests were in the speed range from 1800 rpm to 3000 rpm with a refrigerator temperature of 0°F and an ambient temperature of 110°F. During the series of tests at various speeds the condenser fan speed varied proprotionally with the engine speed by virtue of being mounted on the same shaft whereas the evaporator fan was driven at constant speed because it was driven by a direct current motor.

2. TEST SPECIMEN

The specimen refrigerating unit, Carrier Model D731-9644 was of the plug-type, of nominal one-third ton capacity equipped with an Onan gasoline engine. The unit was designed to refrigerate a 150 cu. ft. walk-in refrigerator, either demountable or non-sectional, in the field where a source of electric power was not available for refrigeration purposes. The non-sectional 150 cu. ft. refrigerator used for capacity tests with various engine speeds was manufactured by Brown Industries of Spokane, Washington. The demountable 150 cu. ft. refrigerator used for capacity tests at various ambient and refrigerator temperatures was manufactured by U. S. Thermo Control Company of Minneapolis, Minnesota. Figure 1 shows an exterior view of the refrigeration unit from the condensing unit end. Figure 2 shows the interior of the condensing unit with the top and one side panel removed. The compressor was directly coupled to and powered by a two cylinder two cycle gasoline engine manufactured by D. W. Ovan & Sons, Inc. of Minneapolis, Minnesota. The condenser was air cooled by a five bladed fan attached to the coupling on the shaft between the compressor and the engine as shown in Figure 2. Air for the condenser was drawn in at the right as seen in Figure 2 and discharged around the engine. The face area of the condenser measured 19 by 20 1/2 inches. A part of the built-in starter-generator is shown back of the air intake grille in Figure 1.

The evaporator coil was mounted horizontally at the bottom of the evaporator section of the unit, seen on the far side of the condensing unit in Figures 1 & 2. The four bladed evaporator fan was 12 inches in diameter and was driven by a 12-volt direct-current motor at a speed of 1900 rpm. This motor was located in the center of the vertical end panel of the cabinet. It drew air in at the bottom of

the evaporator section through the evaporator coil and forced the air straight forward into the refrigerator when installed.

The overall dimensions of the condensing unit section were: width, 41 inches; height, 33 inches; and depth, 25 inches; whereas those of the evaporator section were: width, 28 inches; height, 21 1/4 inches; and depth, 27 inches including the wire guard over the evaporator fan.

3. TEST PROCEDURE

Two series of tests were made of the Carrier Model D731-9644 plug-type refrigerating unit. The unit was mounted in a 150 cu. ft. walk-in refrigerator. The entire system was operated in a room whose temperature could be controlled at the desired level. By adjustment of an internal heat load, the refrigerator temperature was also maintained at the desired level.

For the first series of test, the refrigerating unit was operated in ambient temperatures of 70°F, 90°F, 110°F or 125°F during successive periods and the refrigerator temperature was maintained at 35°F, 0°F and the lowest attainable value without internal heat load during separate tests at each ambient temperature. The engine speed was not adjusted manually during the test, but was regulated by a governor. The 150 cu. ft. demountable warehouse employed for this series of test was manufactured by U. S. Thermo Control Company.

For the second series of test, the refrigerating unit was operated in an ambient temperature of 110°F and the refrigerator temperature was maintained at 0°F. The engine speed was regulated by adjusting the governor setting. Seperate tests were made at engine speeds ranging from 1800 to 3000 rpm in increments of 300 rpm. The non-sectional 150 cu. ft. warehouse employed for this test was manufactured by Brown Industries.

For both series of tests, observation of temperatures was made at 30-minute intervals and observations of speeds, pressures, heat input and fuel consumption were made at 60-minute intervals for at least four hours after a steady state condition was reached.

Prior to each series of test, a reverse heat-flow test was made to determine the rate of heat transfer through the warehouse wall, which constitutes part of the refrigerating load. The refrigerating unit was in place but was not operated during this test. The ambient temperature was held at 35°F and the warehouse temperature was maintained at 135°F while observations of temperatures and the amount of heat required to maintain this temperature difference were made at 30-minute intervals for at least four hours after equilibrium was reached.

Calibrated thermocouples, pressure gages, watt hour meters and other instruments were used for the various measurements.

4. TEST RESULTS

The heat transmission factors of the 150 cu. ft. warehouses used to test the Carrier 1/3-ton refrigerating unit were found to be 23.1 Btu/hr (°F) for the demountable Thermo King warehouse and 27.1 Btu/hr (°F) for the Brown warehouse.

The net refrigerating capacity of the Carrier 1/3-ton unit, Model D731-9644, at design engine and compressor speed is summarized in Table 1 and shown graphically in Figure 3 for a range of ambient temperature and refrigerator temperature. At design conditions of 0°F refrigerator temperature and 110°F ambient temperature the net refrigerating capacity was 3710 Btu/hr or about 93 percent of the nominal rating of one-third ton. At the higher refrigerator temperature of 35°F the net refrigerating capacity was about 8800 Btu/hr for otherwise similar conditions.

Figure 3 shows that the relation between net refrigerating capacity and refrigerator temperature was approximately linear for a given ambient temperature. Conversely, the data in Table 1 can be plotted to show a linear relationship between net refrigerating capacity and ambient temperature for a given refrigerator temperature. In Figure 3 the net refrigerating capacity increased 156 Btu/hr per degree rise in refrigerator temperature on the average for an ambient temperature of 70°F and the corresponding value was 137.5 Btu/hr(°F) for an ambient temperature of 110°F. The net refrigerating capacity decreased 440 Btu/hr for every 10°F rise in ambient temperature above 70°F or eight percent of its capacity at 70°F when the refrigerator temperature was maintained at 0°F. The corresponding decrease for a refrigerator temperature of 35°F was 632 Btu/hr for every 10°F

rise in ambient temperature above 70°F or 5.6 percent of it capacity at 70°F/

Table 1 shows that the air temperature difference across the evaporator was approximately proportional to the net refrigerating capacity as would be expected for constant fan speed and constant air delivery. On the other hand, the air temperature difference across the condenser did not increase in proportion to the net refrigerating capacity, indicating that the heat of compression was lower for lower compression ratios at any given ambient temperature.

Table 1 indicates that the superheat of the refrigerant vapor at the thermal expansion value bulb decreased as the refrigerator temperature decreased. The superheat at the expansion value bulb averaged about 0.5°F at the lowest attainable refrigerator temperature, 2.4°F at a refrigerator temperature of 0°F, and 9.9°F at a refrigerator temperature of 35°F. A comparison of the temperature at the compressor inlet and the saturated suction temperature in tests 1 and 4 in Table 1 suggests that liquid refrigerant could have been entering the compressor at times during these two tests. The observed values of net refrigerating capacity for these two tests, as plotted in Figure 3, however, do not appear to deviate significantly from expected trends.

The engine and compressor speed was not constant during the tests represented by Figure 3 at various ambient and refrigerator temperatures even though the governor was permitted to control the speed during all tests. The average speed ranged from a low value of 1936 rpm for the three tests in an ambient temperature of 90°F to a high value of 2174 rpm for the three tests in an ambient temperature of 110°F. This is a variation of about 11 percent. Considering these variations in speed and their effect on the net refrigerating capacity the curves for ambient temperatures of 70°F, 90°F, and 125°F in Figure 3 should be displaced to the left a little with the greatest shift occurring in the curve for an ambient temperature of 90°F to make the results truly comparative with those shown for an ambient temperature of 110°F.

The results of the capacity tests for a range of engine and compressor speeds from 1800 rpm to 3000 rpm are summarized in Table 2 and shown graphically in Figures 4 & 5. All of these tests were made with an ambient temperature of 110°F and a refrigerator temperature of 0°F.

Figure 5 shows that the net refrigerating capacity increased progressively as the speed was increased from 1800 rpm to 2700 rpm but not proportionally over the entire range, to a maximum value of about 4160 Btu/hr. At an engine speed of 3000 rpm the capacity decreased to about 3700 Btu/hr. In this case the decrease of capacity at 3000 rpm cannot be attributed to an increase in evaporator fan power because the evaporator fan was driven at constant speed for all of the tests. For this unit the shape of the capacity curve in Fig. 4 reflects the effect of the small increase in compression ratio, the change in value action, and the change in discharge refrigerant temperature as the engine and compressor speed was increased.

Table 2 shows that the discharge pressure increased a little as the speed was increased whereas the suction pressure decreased gradually as the speed was increased from 1800 rpm to 2400 rpm. These trends caused a small increase in compression ratio up to a speed of 2400 rpm followed by a gradual decrease in compression ratio at higher speeds. The air temperature difference across the condenser also decreased slowly for speeds above 2400 rpm as shown in Table 2. The data observed during the tests also showed that the temperature of the refrigerant at the compressor discharge decreased for speeds above 2400 rpm. All of these results indicate that the pumping capacity of the compressor was leveling off or decreasing at speeds above 2400 rpm.

On the other hand Table 2 shows that the suction gas temperature was 1.6°F in test 5 at an engine speed of 3000 rpm whereas the corresponding temperatures ranged from 39°F to 57°F for the tests at lower speeds. The low temperature at the compressor suction combined with the low value of superheat at the thermal expansion valve bulb in test 5 suggests that the expansion value may have been permitting liquid refrigerant to approach the compressor suction in this test. If this was occurring, it would tend to lower the useful refrigerating capacity in the refrigerator. Thus the operating conditions are not exactly comparable between test 5 and the remainder of the tests even though they are representative of the performance capabilities of the unit under the speed conditions selected for the investigation. That is, the net refrigerating capacity of the unit at a speed of 3000 rpm might have been higher if the expansion valve had controlled the superheat in the same manner as for lower speeds.

Figure 5 shows the relation between fuel consumption rate and engine speed for the tests at constant ambient and refrigerator temperature. A comparison of Figures 4 & 5 indicates that the gasoline consumption rate increased as the capacity increased and showed a tendency to level off as the capacity of the unit levelled off.

5. DISCUSSION AND CONCLUSIONS

The tests of the Model D731-9644 Carrier 1/3-ton refrigerating unit showed that its capacity at rated speed was about 93 percent of the 1/3-ton rating at an ambient temperature of 110°F and a refrigerator temperature of 0°F. Figure 4 shows that the nominal rating of 4000 Btu/hr could be attained at an engine speed of 2400 rpm and that the maximum capacity of 4160 Btu/hr was attained at an engine speed of 2700 rpm.

Figure 4 shows that the capacity of the unit increased from 3300 Btu/hr at a speed of 1936 rpm to 3750 Btu/hr at a speed of 2174 rpm or about 12 percent of the higher capacity. This is the variation observed in average speed of the test specimen when controlled by the governor during the tests at various ambient temperatures. That is, the data in Figure 4 indicates that the curve plotted in Figure 3 for an ambient temperature of 90°F should be shifted to show capacities about 12 percent higher in order to make it comparable with the plotted data in Figure 3 for an ambient temperature of 110°F. Corresponding changes in the positions of the curves in Figure 3 for ambient temperatures of 70°F and 125°F could be worked out on the same basis.

The data observed at various refrigerator temperatures and ambient temperatures indicated that the relation between unit capacity and either ambient temperature or refrigerator temperature was linear when the other remained constant.

ON

Test Number	
Net Refrigerating Capac	
Engine Speed (a)	
Avg. Refrigerator Temp.	
Avg. Ambient Temp.	1
Discharge Pressure	
Suction Pressure	
Compression Ratio	1
Gasoline Consumption Ra	
Suction Gas Temp.	
Sat. Suction Temp.	
Superheat at Expansion Bulb	
Temperature of Air Ente Condenser	12
Temperature of Air Leav Condenser	13
Air Temp. Difference Ac Condenser	
Temperature of Air Ente Evaporator	-
Tempterature of Air Lea Evaporator	-
Air Temp. Difference Ac Evaporator	

(a) Compressor and Cond was constant at 190
(b) Vacuum, in Hg.

TABLE 1

EFFECT OF REFRIGERATOR AND AMBIENT TEMPERATURE
ON THE CAPACITY OF THE CARRIER REFRIGERATING UNIT D731-9644

Test Number		1	2	3	4	5	6	7	8	9	10	11
Net Refrigerating Capacity,	Btu/hr	2170	5470	11320	2410	4650	10050	2770	3710	8790	2920	7480
Engine Speed (a)	RPM	2019	2020	1954	1957	1939	1913	2198	2208	2115	2165	2082
Avg. Refrigerator Temp.	°F	-24.1	0.1	34.7	-15.1	0.2	35.8	-8.5	-0.1	35.9	-1.1	35.1
Avg. Ambient Temp.	°F	69.5	69.8	69.0	88.9	90.1	90.3	110.7	99.9	110.2	124.9	126.8
Discharge Pressure	psig	86	93	109	114	123	147	160	156	188	191	226
Suction Pressure	"	4.0(b)	0.8	12.0	0.4(b)	2.8	13.6	1.8	2.8	15.1	3.8	16.6
Compression Ratio		7.92	6.95	4.63	8.88	7.87	5.71	10.59	9.76	6.80	11.11	7.69
Gasoline Consumption Rate	lb/hr	3.8	3.6	4.0	3.8	3.6	3.4	3.3	3.6	2.9	3.8	4.3
Suction Gas Temp.	°F	-24.8	29.9	48.5	-17.1	24.8	54.0	24.3	51.0	65.7	57.0	65.1
Sat. Suction Temp.	°F	-28	-19	5	-22	-14	8	-17	-14	11	-12	13
Superheat at Expansion Valve Bulb	°F	0.3	3.3	11.6	0.3	1.1	9.1	0.9	3.4	9.1	1.7	9.7
Temperature of Air Entering Condenser	°F	72.2	72.0	71.1	90.1	91.7	93.4	112.4	109.4	112.6	126.1	129.7
Temperature of Air Leaving Condensor	°F	75.2	77.3	79.9	93.8	96.9	102.0	116.7	14.3	121.2	130.6	138.4
Air Temp. Difference Across Condenser	°F	3.0	5.3	8.8	3.7	5.2	8.6	4.3	4.9	8.6	4.5	8.7
Temperature of Air Entering Evaporator	°F	-23.3	1.2	35.7	-14.5	0.8	36.5	-7.7	1.6	37.4	-0.5	36.2
Tempterature of Air Leaving Evaporator	°F	-24.7	-4.3	24.0	-16.2	-4.0	25.2	-9.7	-2.8	27.5	-3.0	27.5
Air Temp. Difference Across Evaporator	°F	1.6	5.5	11.7	1.7	4.8	11.3	2.0	4.4	9.9	2.5	8.7

(a) Compressor and Condenser Fan speeds were identical with engine speed. Evaporator Fan speed was constant at 1900 rpm
(b) Vacuum, in Hg.

TABLE 2

EFFECT OF CHANGE IN ENGINE SPEED ON THE CAPACITY OF
THE CARRIER REFRIGERATING UNIT, MODEL D731-9644

Test Number		1	2	3	4	5
Net Refrigerating Capacity,	Btu/hr	2980	3580	3960	4160	3810
Engine Speed (a)	RPM	1789	2090	2356	2695	2963
Avg. Refrigerator Temp.	°F	0.2	-0.4	0.4	0.0	0.0
Avg. Ambient Temp.	°F	110.0	110.3	110.0	110.9	110.2
Discharge Pressure	psig	168	168	174	172	173
Suction Pressure	psig	4.0	3.8	3.0	3.2	4.4
Compression Ratio		9.77	9.87	10.66	10.42	9.83
Gasoline Consumption Rate	lb/hr	2.9	3.8	5.1	6.2	6.3
Suction Gas Temp.	°F	38.9	56.6	49.3	42.7	1.6
Sat. Suction Temp.	°F	-11	-12	-14	-13	-10
Superheat at Expansion Valve Bulb	°F	2.2	2.7	6.5	0.4	0.1
Temperature of Air Entering Condenser	°F	113.5	113.6	114.5	113.6	113.5
Temperature of Air Leaving Condenser	°F	117.7	117.8	118.8	117.7	117.4
Air Temp. Difference Across Condenser	°F	4.2	4.2	4.3	4.1	3.9
Temperature of Air Entering Evaporator	°F	-0.6	-0.1	0.9	0.3	0.3
Temperature of Air Leaving Evaporator	°F	-3.9	-2.3	-1.9	-2.7	-2.0
Air Temp. Difference Across Evaporator	°F	3.3	2.2	2.8	3.0	2.3

(a) Compressor and Condenser Fan Speeds were identical with engine speed. Evaporator Fan Speed was constant at 1900 rpm.

Fig. 1

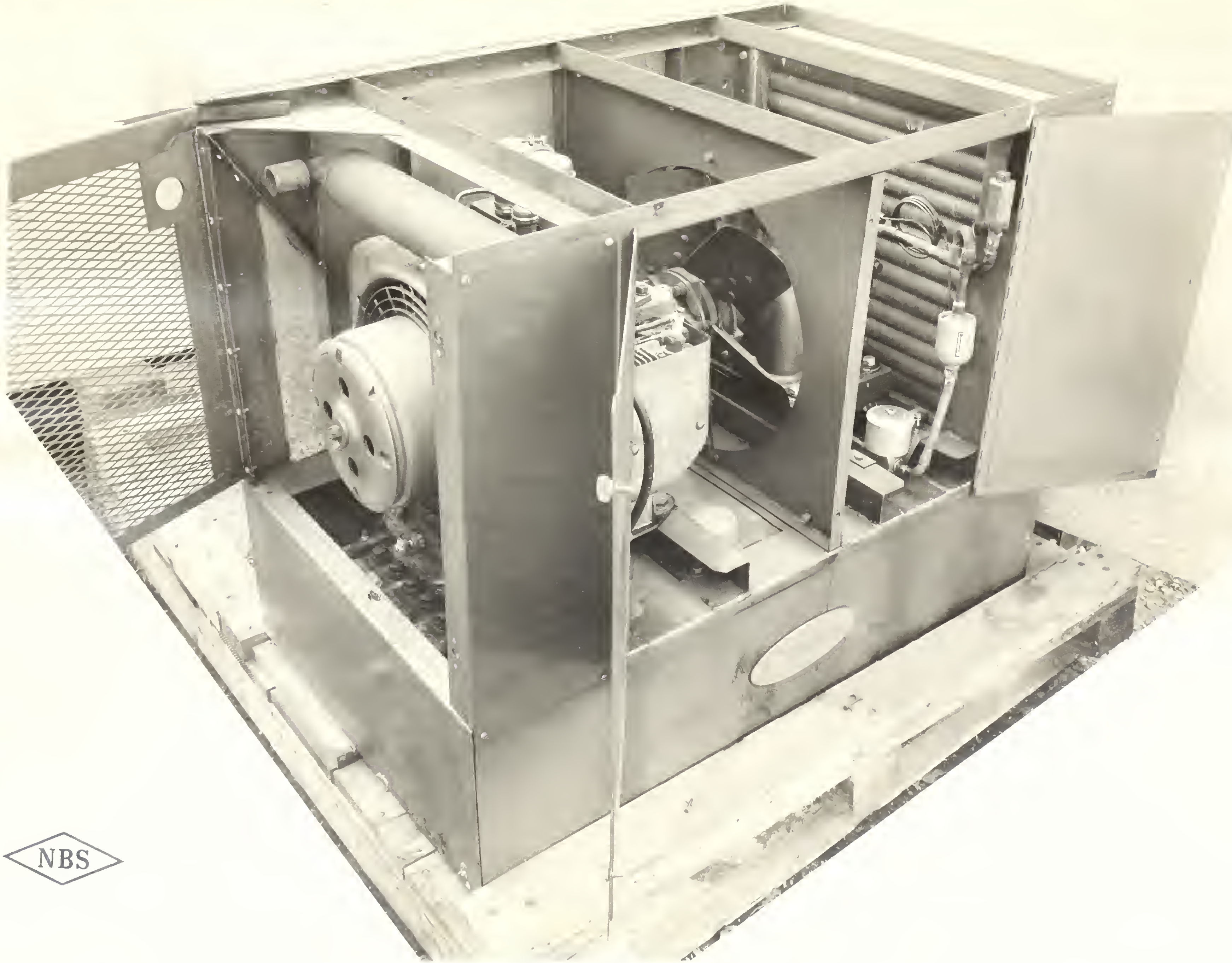
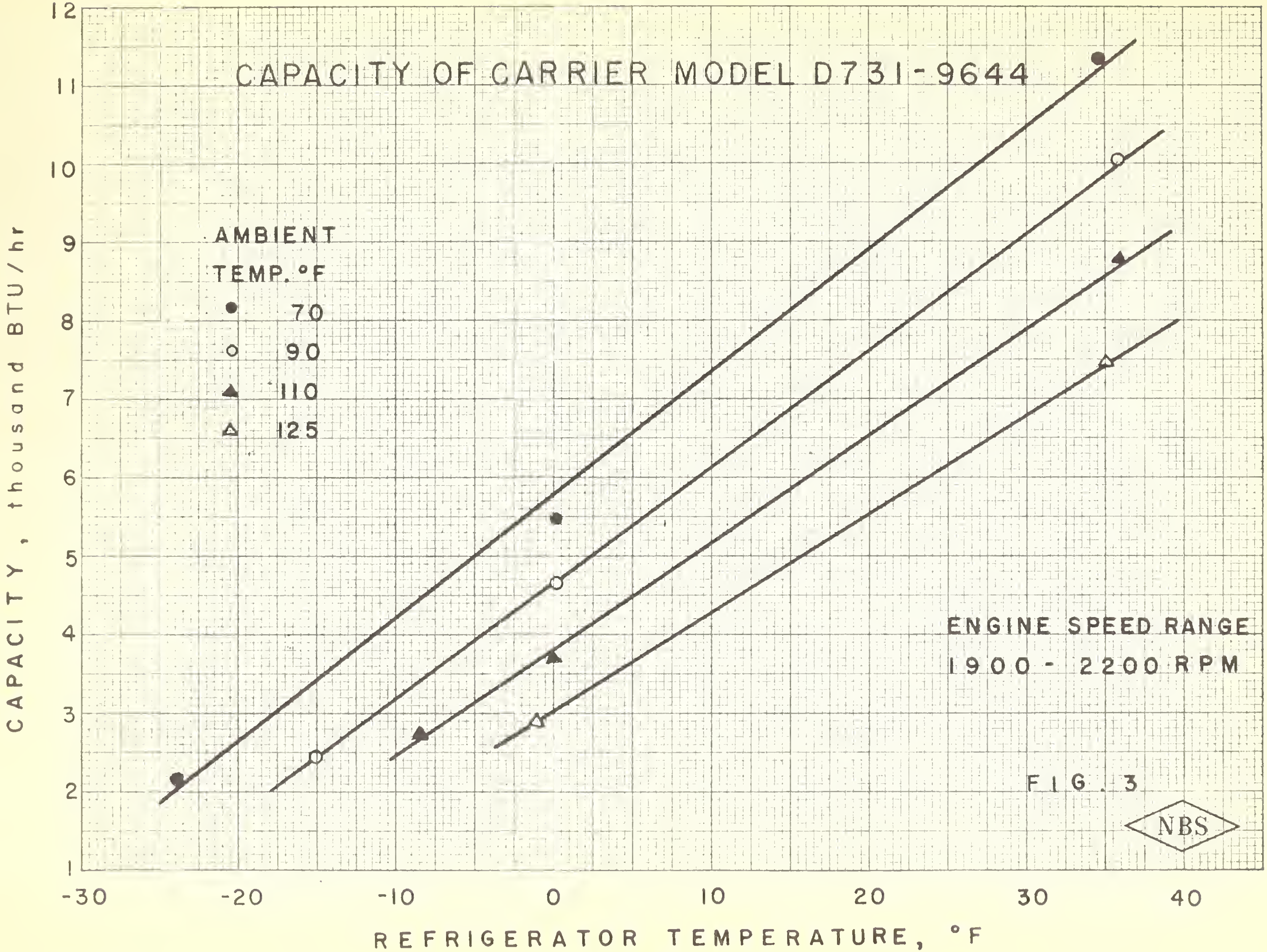


Fig. 2



CAPACITY OF CARRIER MODEL D731-9644
AMBIENT
TEMP. °F
70
90
110
125
ENGINE SPEED RANGE
1900 - 2200 RPM
NBS
12
11
10
9
8
7
6
5
4
3
2
1
-30
-20
-10
0
10
20
30
40
CAPACITY, thousand BTU/hr
REFRIGERATOR TEMPERATURE, °F

FIG. 3

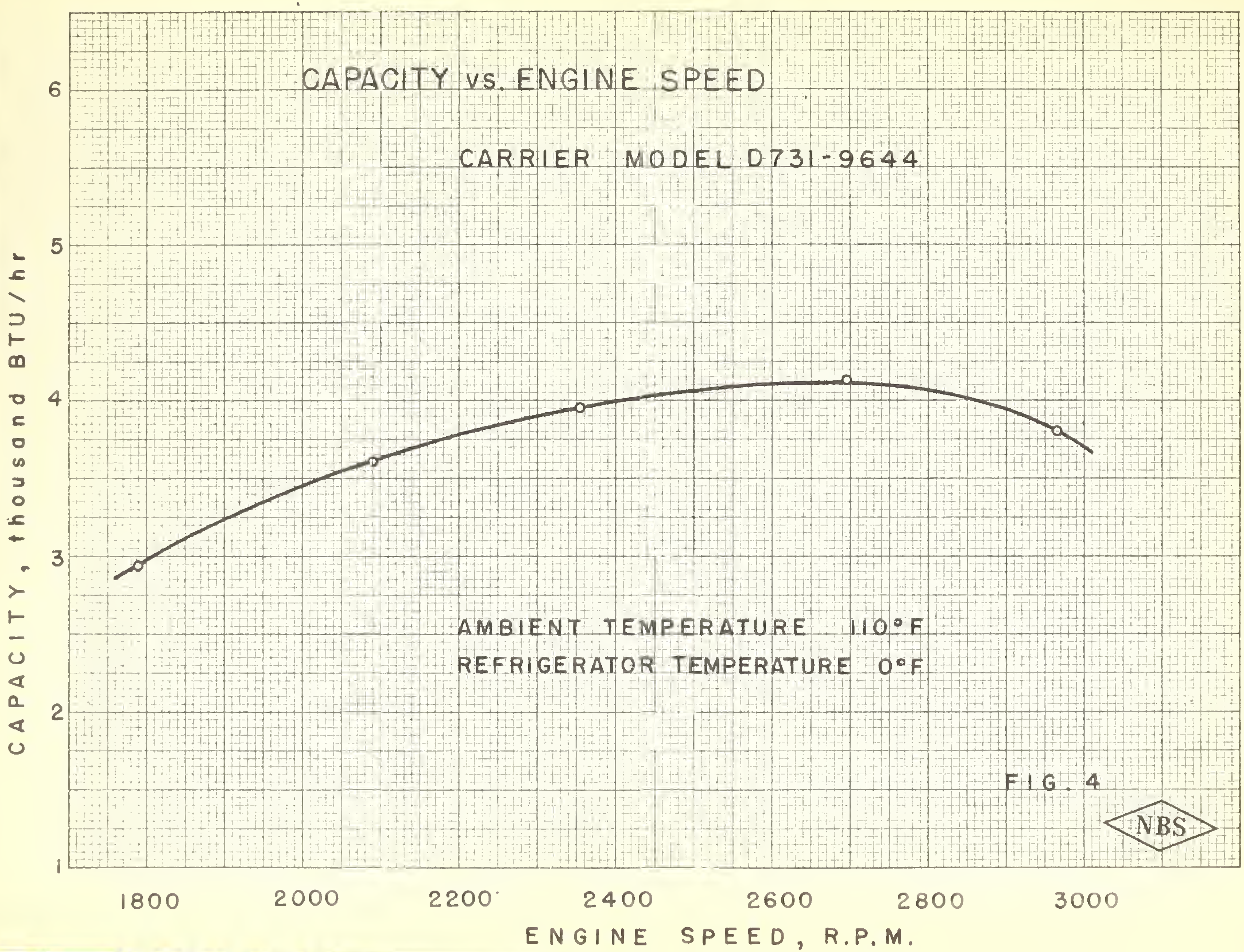
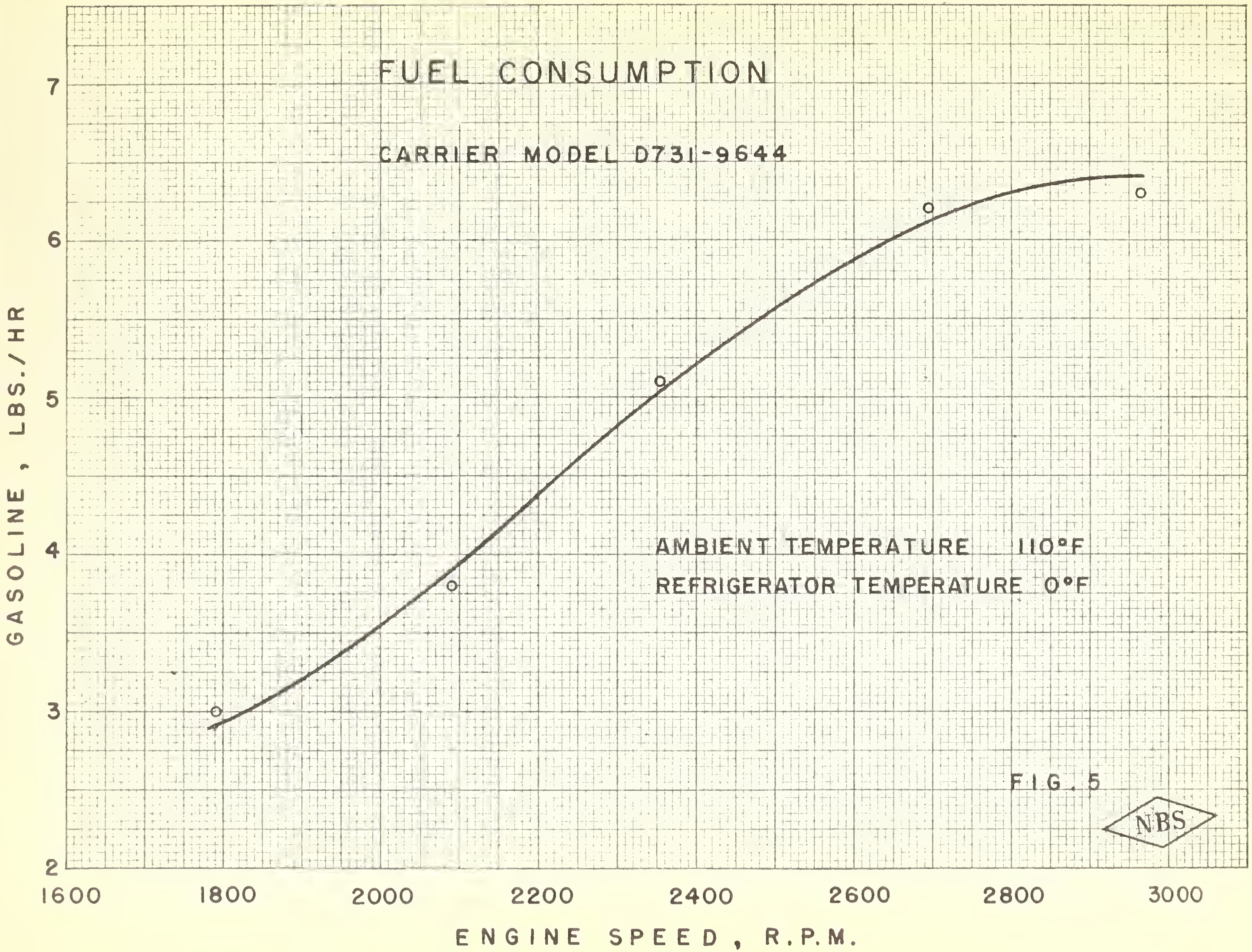

CAPACITY vs. ENGINE SPEED
CARRIER MODEL D731-9644
AMBIENT TEMPERATURE 110°F
REFRIGERATOR TEMPERATURE 0°F
NBS
CAPACITY, thousand BTU/hr
1
2
3
4
5
6
1800
2000
2200
2400
2600
2800
3000
ENGINE SPEED, R.P.M.

FIG. 4



FUEL CONSUMPTION
CARRIER MODEL D731-9644
AMBIENT TEMPERATURE 110°F
REFRIGERATOR TEMPERATURE 0°F
GASOLINE , LBS./HR
ENGINE SPEED , R.P.M.
1600
1800
2000
2200
2400
2600
2800
3000
2
3
4
5
6
7
NBS

FIG. 5

THE NATIONAL BUREAU OF STANDARDS

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The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to Government Agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. A major portion of the Bureau's work is performed for other Government Agencies, particularly the Department of Defense and the Atomic Energy Commission. The scope of activities is suggested by the listing of divisions and sections on the inside of the front cover.

Reports and Publications

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