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U.S. COAST GUARD POLLUTION ABATEMENT PROGRAM: A PRELIMINARY REPORT ON THE EMISSIONS TESTING OF BOAT DIESEL ENGINES

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INTERIM REPORT

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16. Abstract

The exhaust emission concentrations from three GM6-71's and a Cummins VT-350 diesel engines were measured on a dynamometer as a function of engine load. The GM6-71 engines were newly rebuilt by the Coast Guard; the Cummins Engine was in used condition. These engines are used as main power units in Coast Guard boats. The exhaust emission concentrations were reduced to mass emissions by the carbon balance technique. Similar emission levels were obtained from the three rebuilt GM6-71 engines with type HV injectors.

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PREFACE

The work described in this report was performed for the United States Coast Guard as part of an overall effort to evaluate and minimize stack emissions from USCG cutters and boats. The testing was carried out at the USCG dynamometer facility at Base Boston. Assistance in this effort was provided by Mr. C. Hoppen of TSC and by Lt. D. Van Liew, Mr. G. Martinez, Mr. R. Townsend, and the men in the machine shop at Base Boston.

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1. INTRODUCTION

This report documents the experimental procedures, preliminary findings, and recommendations relative to the emissions testing of small marine diesel engines (200-300 brake horsepower), which are used by the U.S. Coast Guard as main engines in boats and as auxiliary generators in larger cutters. This testing is part of a program designed to evaluate the pollution potential of the USCG fleet and to develop cost-effective monitoring and control devices.

In the light of the recommendations of a preliminary report[1], the work has been divided into three tasks:

1. Evaluate emissions from Coast Guard marine diesel engines
2. Establish baseline data so that the effectiveness of various monitoring and control devices may be determined.
3. Evaluate the effects on air quality of mixing water into exhaust, as is common practice in the Coast Guard fleet.

2. EXPERIMENTAL WORK

2.1 APPROACH

In order to accomplish the three tasks described in Section 1, the following tests are being performed:

1. Dynamometer testing of rebuilt engines, of similar type and design, to establish baseline data.
2. Dynamometer testing of used engines as available, to establish emissions-level changes over the engine's lifetime.
3. Dynamometer testing to evaluate the effectiveness of internal engine modifications, such as injector geometry and timing, as control techniques.
4. Dynamometer testing of emissions before and after water-exhaust mixing, to determine whether this approach reduces the emissions level.
5. Field testing of engines under typical operating conditions, both as main engines in boats and as auxiliary generators. (This field testing has been completed and a report issued; see Reference 2.)

This interim report focuses on the results obtained to date in the first two test areas.

2.2 INSTRUMENTATION

The pollutants being measured and the techniques being used in this program are:

Carbon monoxide, Carbon dioxide	Non-dispersive infrared
Total hydrocarbons	Total hydrocarbon analyzer
Oxides of nitrogen	Chemiluminescence
Oxygen	Paramagnetic
Smoke	Ringelmann chart and opacity meter

The necessary instruments have been assembled into a caster-mounted cabinet by Scott Research Labs, according to TSC specifications. This cabinet, shown in Figure 1, contains all the pumps, valves, flowmeters, and fittings necessary for emissions testing to EPA-approved methods. The following paragraphs briefly describe each instrument and its operating principle.

2.2.1. Non-Dispersive Infrared Analyzer (MSA Model 202)

The NDIR instrument measures carbon monoxide and dioxide by means of their absorption in the infrared portion of the spectrum. With a beam chopper, radiation from an infrared source is alternately passed through a cell filled with a sample gas and a reference cell filled with a non-absorbing gas. When the sample gas contains an infrared-absorbing component, part of the radiation is absorbed. The amount transmitted through each cell is measured by a pressure- or photosensitive detector. The pressure-sensitive detector is made selective by filling it with a particular absorbing component; the photo-sensitive detector can be made selective with a bandpass filter.

The CO analyzer is equipped with a dual sample cell, which permits four ranges of CO to be measured: 0 to .05%, 0 to 0.2%, 0 to 2%, and 0 to 10%. The CO_2 analyzer has three ranges: 0 to 3%, 0 to 10%, and 0 to 15%.

2.2.2 Total Hydrocarbon Analyzer (Scott Model 215B)

Total hydrocarbons are measured by means of a flame ionization detector (FID) and associated electronics.

The FID measures the increase in ion current produced by burning the hydrocarbons from exhaust in a clean hydrogen flame. Hang-up of heavy hydrocarbons in the sample line is avoided by heating the line and detector to 350°F. This instrument is capable of measuring total hydrocarbon (THC) concentrations from 1 ppm to 100,000 ppm in eleven switch-selectable ranges.

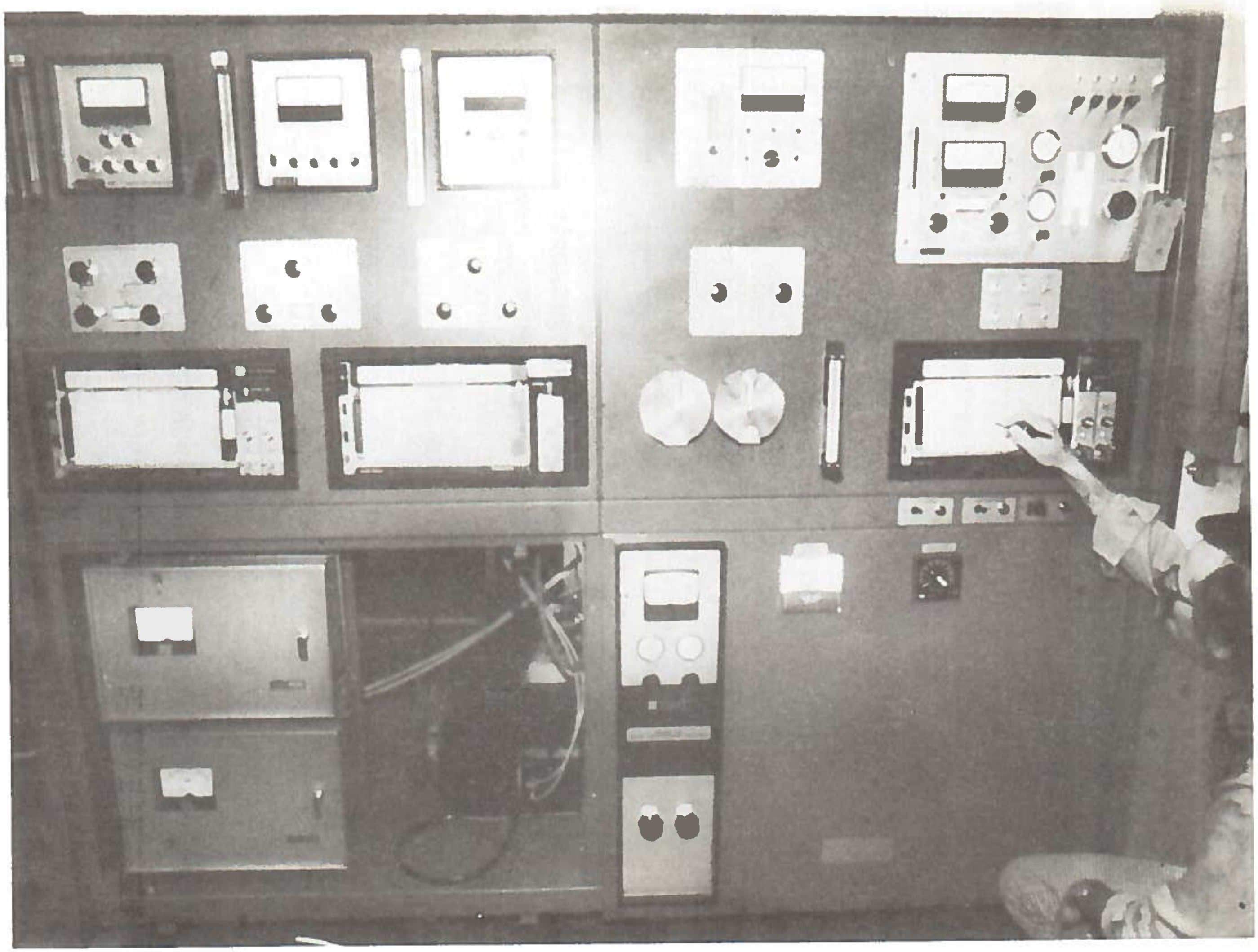

Figure 1. Cabinet Incorporating Emissions-Measurement Instruments

2.2.3 Chemiluminescence Analyzer (Scott Model 125)

A chemiluminescence analyzer determines the concentration of nitric oxide (NO) in a gas sample by treating the gas with ozone to convert any NO to the excited molecule NO_2^*, and then measuring the quantity of light produced by the decay of this molecule to its ground state of NO_2. If total oxides of nitrogen (NO_x) are to be measured, the sample gas is heated to 1400°F in a converter to change all NO_x to NO.

The analyzer is composed of a vacuum pump, ozonator, reaction chamber, and photomultiplier tube, with the necessary plumbing and electronics. The instrument has seven switch-selectable settings, with ranges from 0-2.5 ppm to 0-10, 000 ppm; its sensitivity is better than 1 ppm.

2.2.4 Paramagnetic Oxygen Analyzer (Scott Model 105)

Oxygen is a paramagnetic gas, and an instrument has been designed to make use of this characteristic. When a laminar flow of gas containing oxygen (O_2) is directed through a magnetic field, a pressure gradient is developed across the gas stream. A pressure-sensitive detector produces a current proportional to the oxygen in the gas sample. This instrument has four ranges: 0 to 1%, 0 to 5%, 0 to 10%, and 0 to 25%.

2.2.5 Ringelmann Smoke Chart; Opacity Smokemeter (Atlantic Research Model 106)

The Ringelmann smoke chart, shown in Figure 2, is used for visual comparison with a smoke plume. The five increments are referred to as Ringelmann numbers; a trained observer can identify densities to half a Ringelmann number.

An opacity smokemeter determines the density of exhaust smoke by measuring the attenuation of a light beam directed across the exhaust stream. It is composed of a light source and a detector, with appropriate readout electronics. The instrument can measure from 1 to 100% opacity with a calibration accuracy of ±1%.

PLIBRICO SMOKE CHART

RINGELMANN TYPE

INSTRUCTIONS

This miniature Ringelmann smoke scale will enable the observer to conveniently grade the density of smoke issuing from the stack.

The scale should be held at arm's length at which distance the dots in the scale will blend into uniform shades.

Then compare the smoke (as seen through the hole) with the chart, determining the shade in the chart most nearly corresponding to the shade or density of the smoke. Experienced observers often record in half chart numbers. By recording the changes in smoke density, the average "percentage of smoke density" for any period of time can be determined.

Observer's line of observation should be at right angles to the direction of smoke travel.

Observer should not be less than 100 ft. nor more than ¼ mile from the stack.

Observer should avoid looking towards bright sunlight. The background immediately beyond the top of the stack should be free of buildings or other dark objects.

Figure 2. Ringelmann Smoke Chart

2.2.6 Recorders (Scott Model 200)

Strip-chart recorders are used to produce permanent records of all measurements. The recorder is basically a two-channel null-balancing dc potentiometer that accepts the electrical outputs from the gas analyzers and draws an analog record on a continuous strip chart.

Three dual-channel recorders are built into the gas-analysis system. The chart speed is selectable in ten ranges from 3 to 360 inches per hour.

2.2.7 System Operation

As was mentioned earlier, all the instruments (except the smoke-density instrumentation) are contained in a single cabinet. The flow-control and sample-conditioning systems are shown in Figure 3.

The system requires a 110-V, 60-Hz supply for operation; the maximum power requirement is 6 kW.

Several problems were encountered during system-acceptance testing and checkout:

- Destructive overheating of the FID heated-sample line, due to improper flow and temperature control.
- Slow response time in the NO analyzer, due to out-of-specification flowmeters.
- Lack of linearity in the CO NDIR analyzer, due to an improperly adjusted amplifier in the readout electronics.
- Failure of the sampling pump in the NO line.
- "Poisoning" of the NO_x converter by the reducing atmosphere of diesel exhaust.

All these problems were resolved by replacement of faulty parts or by improved operating techniques.

Power must be applied to all the instruments at least one hour before the start of testing, to allow the instrumentation and the heated elements of the HC analyzer to reach operating temperatures.

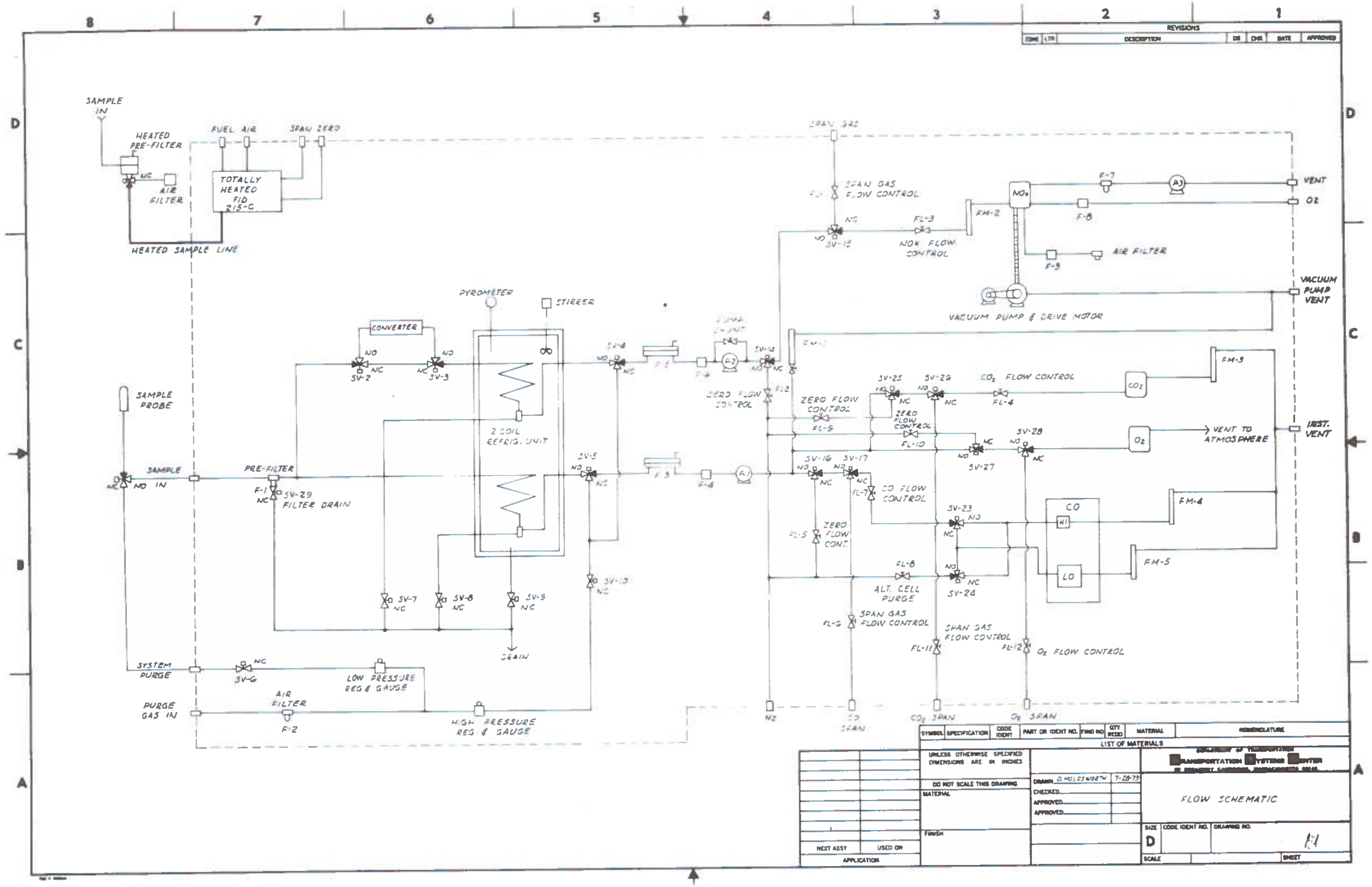

Figure 3. Flow Schematic for Emission Measuring Instrumentation

Approximately thirty minutes are required for the refrigerated water bath that drys the gas sample to attain its operating temperature of 0°C.

Before the start of testing, the flow rates of all calibration, zero, and sample gases must be adjusted to their nominal values for proper operation of each instrument. During testing, these flow rates must be continuously monitored and adjusted as calibration and zero gases are depleted and the sample-line particulate filters become contaminated. These particulate filters were changed at least twice during the tests on each engine.

The flow rate and temperatures of the heated elements of the hydrocarbon analyzer must be continuously monitored to ensure proper operation of the system and prevent overheating of the sample line. It was found that the line could easily become crimped, causing loss of flow and destructive overheating.

Periodic purging of the refrigerator coils is necessary to prevent build-up of condensates.

Two technical personnel were required for the diesel-engine testing described in this report. One person monitored the engine, fuel flow, and dynamometer; the other checked the emission instruments and recorded the data.

2.3 MEASUREMENTS AND RESULTS

2.3.1 Measurements and Data Reduction

Initial measurements of diesel-engine emissions are being made at U.S. Coast Guard Base Boston. Their dynamometer facility, shown in Figure 4, is equipped with a Clayton waterbrake-type dynamometer capable of absorbing up to 700 brake-horsepower at 4000 rpm. The dynamometer is primarily used to break in rebuilt engines, but is also used to test engines whose performance has been questioned by a boat crew.

All boat engines are rebuilt approximately every 4000 hours. When an engine is rebuilt, it is fitted with new cylinder liners, pistons, valves, and any other part which is out-of-specification.

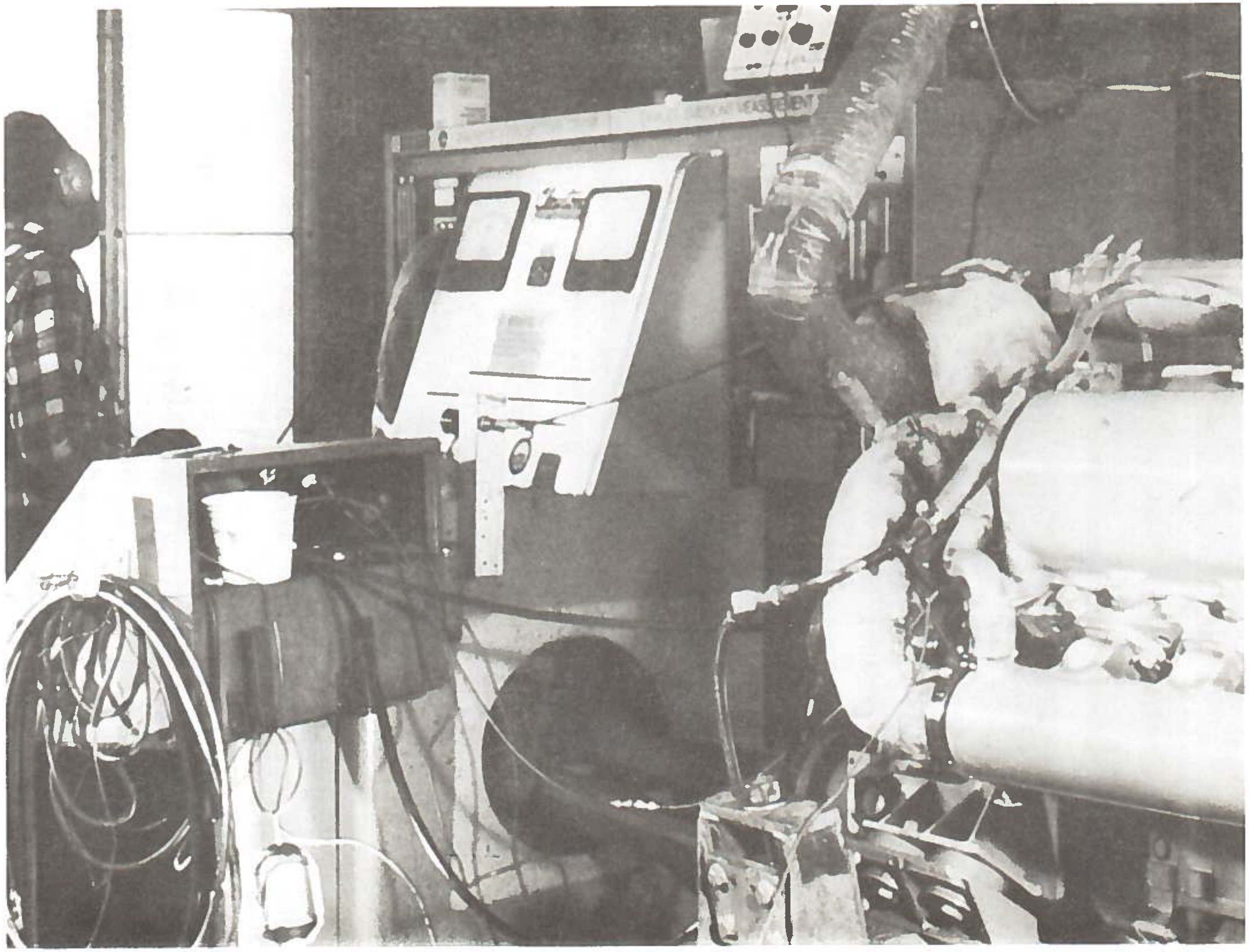

Figure 4. USCG Dynamometer Facility

The engine is then broken in on the dynamometer for approximately four hours; the power level is increased each hour until it reaches the rated output of the engine. The same regime is followed for used engines; if a problem is encountered, an effort is made to evaluate it, repair the engine, and continue the test. The Coast Guard logs all test information on a data sheet such as that shown in Figure 5.

For emissions testing of both rebuilt and used engines, the engine is first allowed to come to equilibrium at the power level under test. All instruments are then zeroed and calibrated, and measurements made for at least five minutes to ensure steady-state emissions. At the end of the test, all instruments are again zeroed and calibrated. The load is held constant for about one hour, and the test is then repeated. The results of the two tests are compared and consistency checked.

Each engine is usually tested in six operating modes, from idle (600 rpm, 0 bhp) to full load (2000 rpm, 185 bhp). Since two tests are run in each mode, a total of twelve measurements of CO, CO_2, O_2, NO, NO_x, and THC are made for each engine.

TSC records raw emissions and test data on data sheets (Figure 6) and on recorder strip charts (Figure 7). This data is transferred to working sheets (Figure 8) for further data reduction by computer. Using techniques described in Reference 3, the computer corrects dry emissions to wet, where appropriate, and calculates the mass emissions.

Fuel flow rates were initially measured with fuel flowmeters of the positive-displacement type. Since these meters have the inherent problems of limited operating range, poor readability, and susceptibility to air leaks; a positive system of fuel-flow measurement was used. This system consisted of a 55-gallon barrel on a scale, to which the engine fuel supply and return lines were connected. The weight loss, as measured by the scale, is a direct reading of the fuel used by the engine. The scale was accurate to ±0.25 lb (0.035 gal).

ENGINE TEST REPORT

Date 3-7-73
Repair Order Number N/A
Unit Number 6A-20533
Model Number 6072 A

A PRE-STARTING

1. PRIME LUBE OIL SYSTEM	2. PRIME FUEL SYSTEM	3. ADJUST VALVES AND BRIDGES	4. TIME INJ.	5. ADJ. GOV.	6. ADJUST INJ. RACKS
✓	✓	✓	✓	✓	✓

B BASIC ENGINE RUN-IN

TIME AT SPEED	TIME START	TIME STOP	RPM	BHP	WATER TEMP.	LUBE OIL PRESS.
35	0840	0915	1200	22	165	44
60	0915	1015	1400	68	174	42
60	1015	1115	1600	105	175	44
60	1115	1215	1800	142	175	45

C BASIC RUN-IN INSPECTION

1. Check oil at rocker mechanism	✓
2. Inspect for lube oil leaks	✓
3. Inspect for fuel oil leaks	✓
4. Inspect for water leaks	✓
5. Check and tighten all external bolts	✓
6.	

D INSPECTION AFTER BASIC RUN-IN

1. Tighten Cylinder Head & Rocker Shaft Bolts	✓	4. Adjust Governor Gap	✓
2. Adjust Valves (Hot)	✓	5. Adjust Injector Racks	✓
3. Time Injectors	✓	6.	

E FINAL RUN-IN

TIME START	TIME STOP	TOP RPM NO LOAD	TOP RPM FULL LOAD	BHP	AIR BOX PRESSURE FULL LOAD	EXHAUST BACK PRESSURE F/L	CRANKCASE PRESSURE F/L
1315	1330	2050	2000	185	12.0	4.5	3.0

BLOWER INTAKE RES. - F/L	FUEL OIL PRESSURE RET. MAN. F/L	WATER TEMP. FULL LOAD	LUBE OIL TEMP. F/L	LUBE OIL PRESSURE FULL LOAD	LUBE OIL PRESSURE IDLE	IDLE SPEED
16.0	50	178	188	46	40	650

F INSPECTION AFTER FINAL RUN

1. Inspect Air Box, Pistons, Liners, Rings	✓	6. Tighten Oil Pump Bolts	✓
2. Inspect Blower	✓	7. Inspect Oil Pump Drive	✓
3. Check Generator Charging Rate	✓	8. Replace Lube Filter Elements	✓
4. Wash Oil Pan, Check Gasket	✓	9. Tighten Flywheel Bolts	✓
5. Clean Oil Pump Screen, Remove Cloth	✓	10. Rust Proof Cooling System	✓

REMARKS:

Final Run OK'd [signature] Dynamometer Operator [signature] Date 3-7-73

NOTE; Operator must initial each check and sign this report.

TREASURY DEPARTMENT
U.S. COAST GUARD

FORM CGD1-10270-1(Rev.8-65)

Figure 5. Sample Coast Guard Test Data Sheet

Date 3-2-73

ENGINE DATA: Mfr. GM Type 6071 Serial 6A60144 Rating 200 hp @ 2000 rpm Injector HV-7

HISTORY: Total Engine Operating Hrs. Newly Overhauled Total Eng. Hrs. Since Major Overhaul ______ Total Eng. Hrs. Since Top Overhaul ______

TEST OPERATING CONDITIONS

Time	Mode	rpm Dyno	rpm Engine	Oil Temp.	Oil Press.	Water Temp. Dyno	Water Temp. Engine	Water Press. Dyno	Water Press. Engine	Fuel Usage (g/hr)	hp	Smoke No.
0835	1	1220	1400	180	45	100	170	50	NA	6.24	67.5	2.0
0930	1	1240	1425	185	45	100	170	50	NA	624	72.0	1.5
0955	2	1050	1200	160	45	65	155	48	NA	4.80	20.0	2.0
1005	3	1400	1600	185	46	120	170	49	NA	8.25	110.0	2.0
1042	3	1400	1600	188	46	120	170	49	NA	8.25	108.0	2.0
1050	4	1560	1780	192	47	142	173	50	NA	10.60	150.0	1.0
1130	4	1530	1770	194	47	144	174	47	NA	10.60	140.0	1.0
1133	5	1700	1975	195	48	160	178	48	NA	1440	185.0	2.0

METEOROLOGICAL DATA

Time	Mode	Amb. Dry Bulb	Temp. Wet Bulb	Bar. Press.	Rel. Humid. (%)
0900	1	66	53	30.40	40
1000	1	67	54	30.41	42
1025	3	67	53.5	30.42	41
1105	4	67	53.5	30.45	41

OTHER DATA

Figure 6. Sample TSC Test Data Sheet

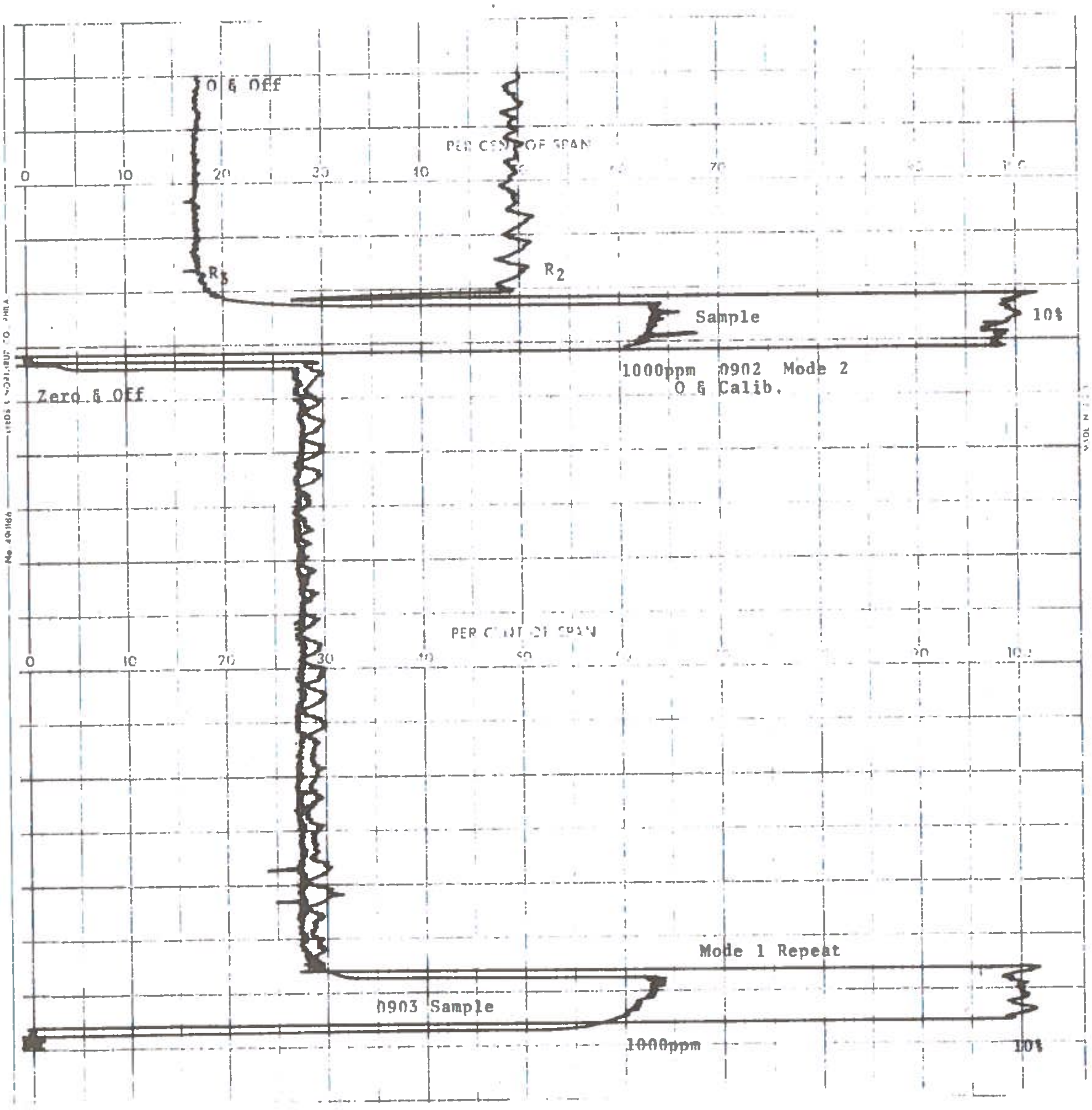

Figure 7. Sample Recorder Output

Engine GM 6071 Serial 6A60144 Rating 200 hp @ 2000 rpm Overhaul Status Newly Overhauled DATE 3-2-73

Mode	rpm Engine	Dyno	hp	Oil Temp.	Oil Press.	Water Temp.	Water Press.	Feul Usage (g/hr)	CO (ppm)	CO_2 (%)	O_2 (%)	NO (ppm)	NO_2 (ppm)	THC (ppm)	Meteorological Data Dry Bulb	Wet Bulb	Rel. Humid.	Bar. Press.
1	1400	1220	67.5	180	45	170	50	6.24	250	3.4	15.35	590	20	1600	66	53	40	30.40
1	1425	1240	72	185	45	170	50	6.24	240	3.4	15.25	610	22	1750				
2	1200	1050	20	160	45	155	48	4.80	460	17.0	17.25	240	62	1100	67	54	42	30.41
3	1600	1400	110	185	46	170	49	8.25	210	4.2	14.25	790	10	1250				
3	1600	1400	108	188	46	170	49	8.25	210	4.15	14.35	795	10	1200	67	53.5	41	30.42
4	1780	1560	140	192	47	173	50	10.60	370	5.85	12.85	900	0	1300				
4	1770	1530	135	194	47	174	47	10.60	320	5.75	12.75	920	0	1150	67	53.5	41	30.45
5	1975	1700	185	195	48	178	48	14.40	1080	6.1	11.40	965	0	1200				

Figure 8. Sample TSC Work Sheet

2.3.2 Results

Three GM 6-71 rebuilt engines and one used Cummins VT-350 have been emissions-tested to date. Table 1 gives the corrected concentration data and mass-emission for the three 6-71 engines, which were run under similar operating conditions. The data on the Cummins VT-350 was not reduced to mass-emissions numbers, because one of the fuel meters failed. The raw concentration data for this engine are given in Table 2. No reliable data could be obtained on THC for this engine, due to the failure of the heated sample line.

Figure 9 gives horsepower-versus-emissions curves for the three GM 6-71 engines. Figure 10 gives their brake-specific fuel consumption (BSFC). Table 3 gives their Ringelmann smoke readings (the average of two observers' results). The opacity meter was not yet available when these tests were run.

During emissions testing, sound-pressure readings were taken at various distances from the 6-71 engines, and also from a GM 6V-53. These readings are given in Appendix A, along with the daily unprotected noise-exposure limits permitted by the National Occupational Health Act and the Walsh-Healey Contracts Act.

So far, the data from the three identical rebuilt engines have been similar. The trends of the emissions curves are reproducible from engine to engine; that is the brake-specific emissions of CO are lowest in the mid-ranges, THC increases as the power increases, and NO remains constant after about 25% power has been reached. These curves and the curve for BSFC make it evident that boats are most efficiently operated through the mid-power ranges. All the emissions are within the normal ranges for older diesel engines of this design. The relatively high THC levels are due primarily to the crown injectors used in these engines. With crown injectors, a significant amount of fuel remains below the valve in the injector tip. This fuel enters the combustion chamber after primary ignition, and is not burned; this results in high hydrocarbons, smoke, and odor[4]. These injectors have no effect on NO_x levels.

The highest-level pollutant produced by all diesel engines is oxides of nitrogen; it is also the most difficult to control.

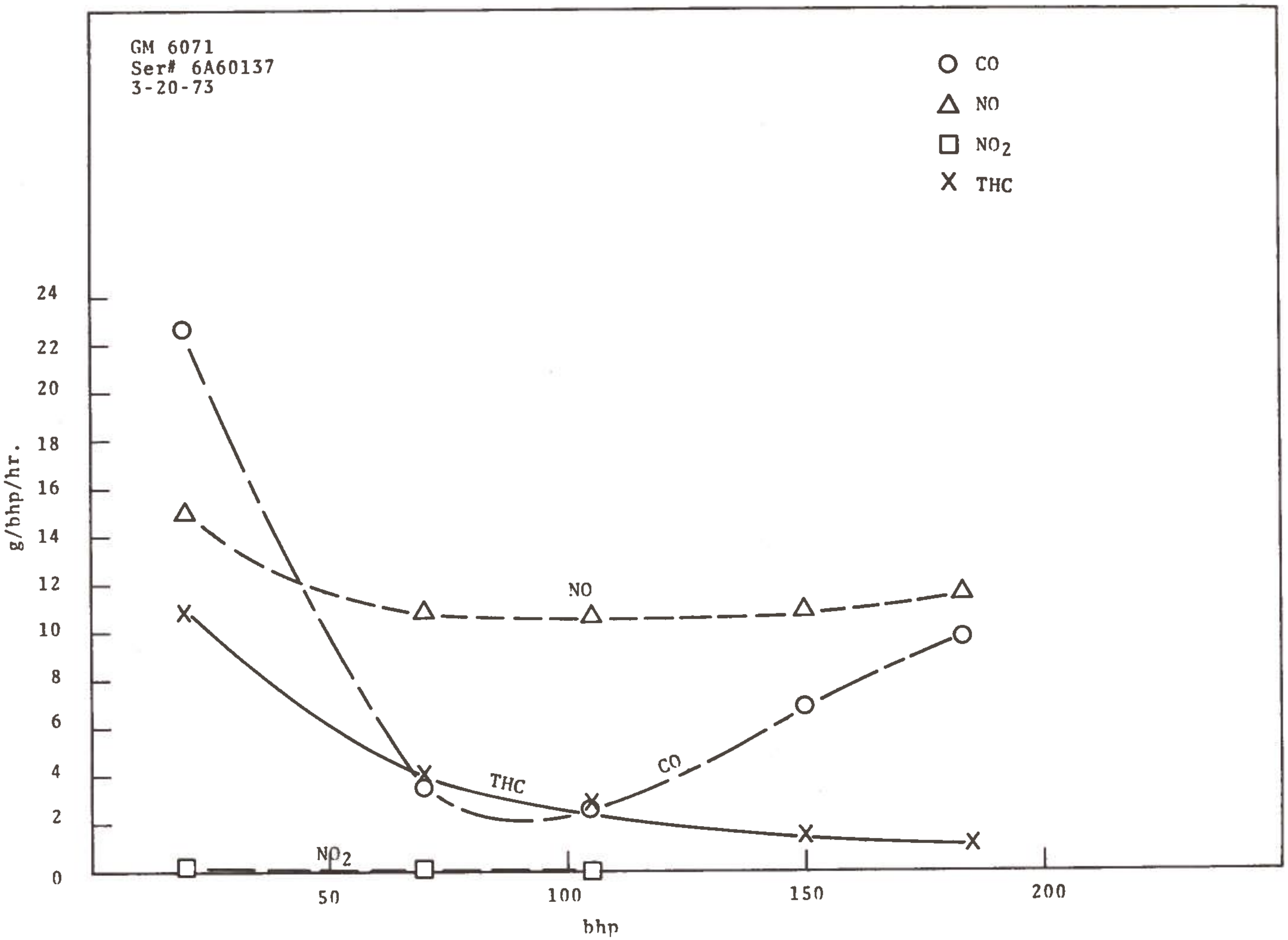

Figure 9a. CO, NO, NO_2, and THC Levels vs. Horsepower for GM 6-71 Engine No. 6A60137

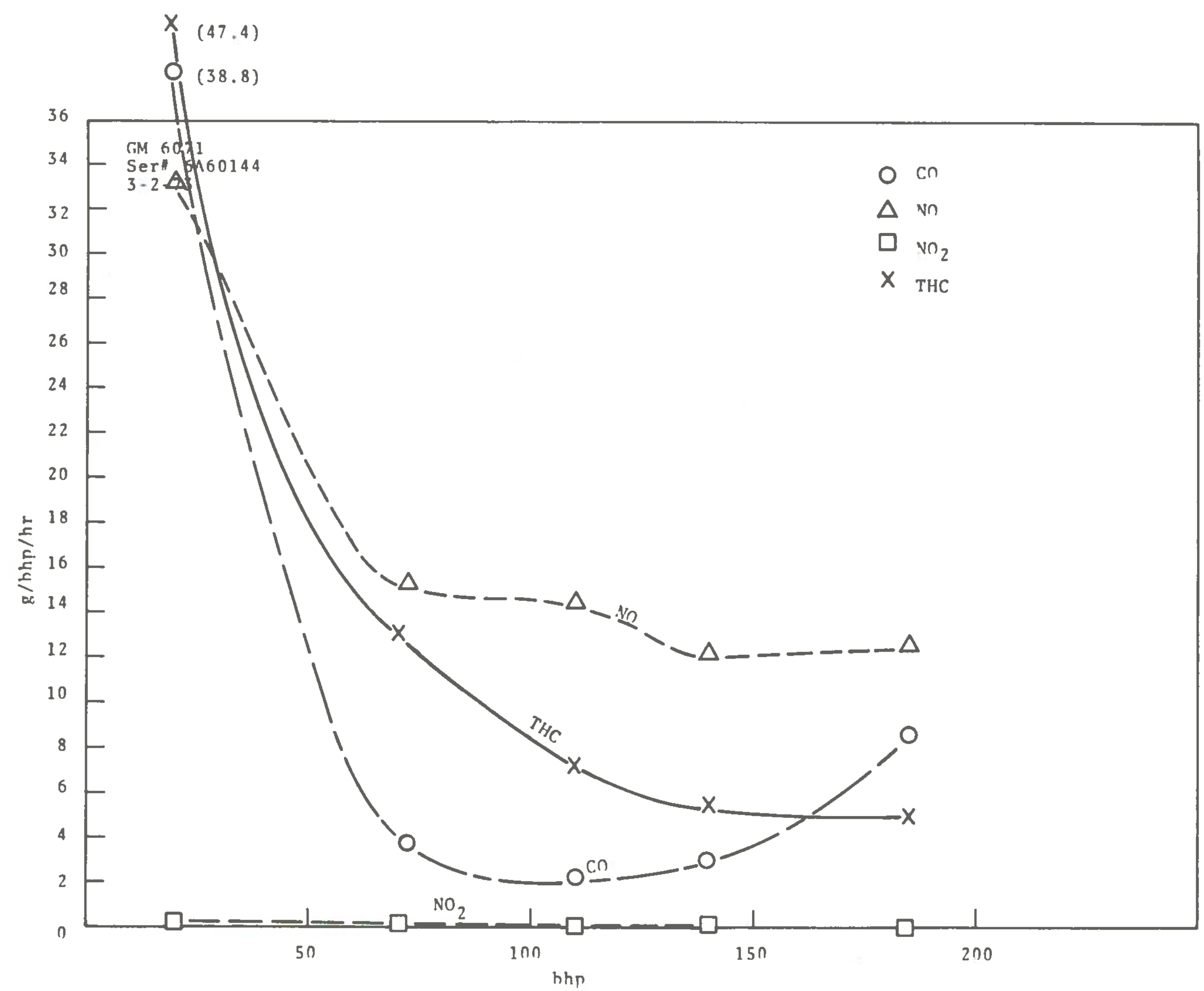

Figure 9b. CO, NO, NO_2, and THC Levels vs. Horsepower for GM 6-71 Engine No. 6A60144

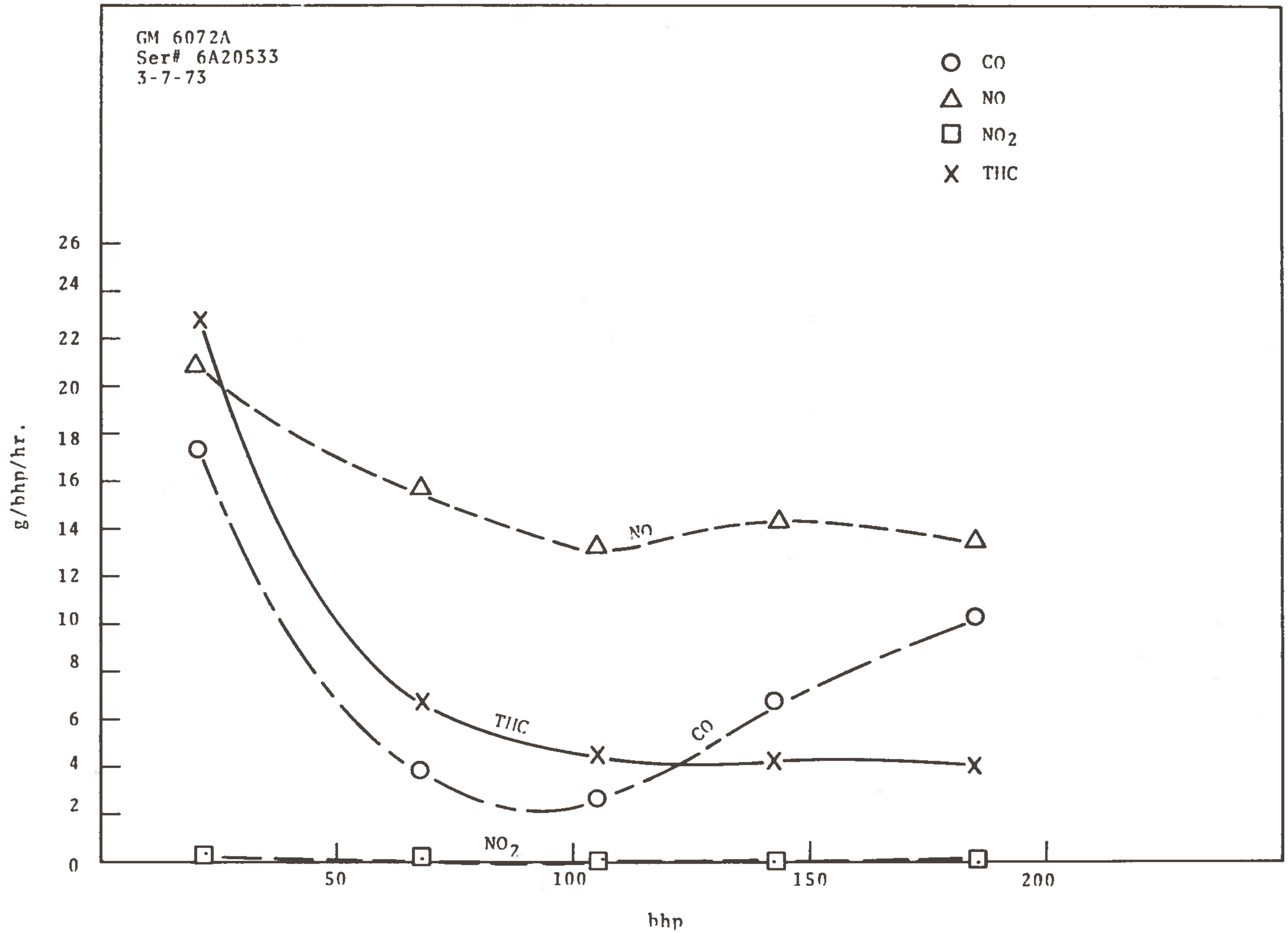

Figure 9c. CO, NO, NO_2, and THC Levels vs. Horsepower for GM 6-71 Engine No. 6A20533

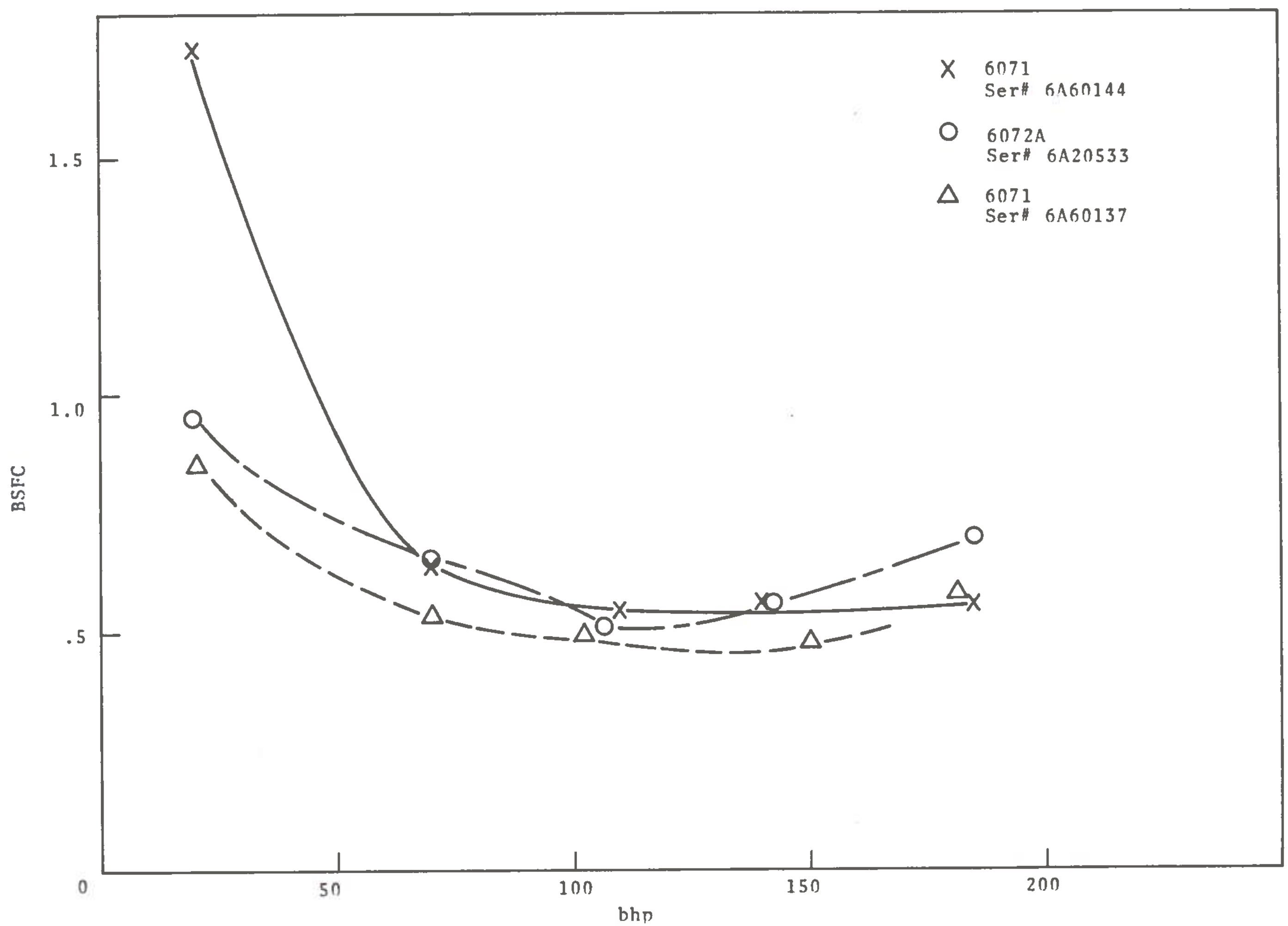

Figure 10. Brake Specific Fuel Consumption for Three GM 6-71 Engines

TABLE 1. MASS EMISSION DATA

a. Engine Model 6071, Serial No. 6A60137

					Dry Concentrations Corrected to Wet							Mass Emission							
												lb/hr				g/bhp/hr			
Date	Time	Mode	hp	rpm	Correction Factor	CO (ppm)	CO_2 (%)	O_2 (%)	NO (ppm)	NO_2 (ppm)	THC (ppm)	CO	NO	NO_2	THC	CO	NO	NO_2	THC
3/20	0920	1	idle	700	.9855	1123	0.99	18.72	36	47	770	1.72	.092	.013	.590	-	-	-	-
3/20	0940	2	20	1200	.9803	490	1.62	18.92	191	59	480	0.97	.624	.011	.476	22.0	14.1	.250	10.8
3/20	1005	2	18	1200	.9803	451	1.62	19.02	188	55	440	0.898	.617	.011	.438	22.6	15.56	.277	11.0
3/20	1035	3	70	1380	.9654	251	3.28	16.51	459	24	590	.567	1.703	.002	.666	3.67	11.04	.13	4.32
3/20	1105	3	71	1380	.9654	241	3.28	15.93	465	22	440	.547	1.736	.002	.499	3.49	11.1	.13	3.19
3/20	1142	4	102-105	1600	.9659	249	4.21	14.64	603	14	480	.595	2.373	.001	.574	2.60	10.5	.004	2.84
3/20	1220	4	101-103	1600	.9607	231	3.79	14.65	610	12	470	.611	2.66	.001	.623	2.72	11.8	.004	2.77
3/20	1245	5	150-152	1800	.9522	857	4.67	13.09	747	0	380	2.55	3.66	0	.566	7.67	11.01	0	1.70
3/20	1310	5	150	1800	.9506	780	4.85	13.07	746	0	260	2.25	3.53	0	.375	6.79	10.7	0	1.135
3/20	1330	6	182	1800	.9439	982	5.57	11.52	755	0	250	3.72	4.71	0	.474	9.29	11.7	0	1.18

b. Engine Model 6071, Serial No. 6A60144

					Dry Concentrations Corrected to Wet							Mass Emission							
												lb/hr				g/bhp/hr			
Date	Time	Mode	hp	rpm	Correction Factor	CO (ppm)	CO_2 (%)	O_2 (%)	NO (ppm)	NO_2 (ppm)	THC (ppm)	CO	NO	NO_2	THC	CO	NO	NO_2	THC
3-2-73	0855	1	67.5	1400	.9655	241	3.28	14.82	570	19	1600	.626	2.429	.002	2.074	4.2	16.33	.013	13.45
3-2-73	0930	1	72	1425	.9655	232	3.28	14.72	570	19	1600	.601	2.430	.002	2.074	3.78	15.32	.012	13.07
3-2-73	0955	2	20	1200	.9800	451	1.67	16.90	235	61	1100	1.71	1.469	.011	2.088	38.8	33.3	.249	47.4
3-2-73	1005	3	110	1600	.9587	201	4.03	13.66	757	10	1250	.573	3.548	.001	1.780	2.36	14.64	.004	7.35
3-2-73	1042	3	108	1600	.9592	201	3.98	13.76	763	10	1200	.581	3.616	.001	1.730	2.44	15.2	.004	7.27
3-2-73	1050	4	140	1780	.9449	350	5.53	12.14	850	0	1300	.937	3.751	.0	1.743	3.04	12.16	.0	5.65
3-2-73	1130	4	135	1770	.9458	303	5.44	12.06	870	0	1150	.828	3.918	.0	1.574	2.78	13.17	.0	5.29
3-2-73	1133	5	185	1975	.9427	1018	5.75	10.74	909	0	1200	3.536	5.197	.0	2.084	8.67	12.75	.0	5.11

TABLE 1. MASS EMISSION DATA (CONT.)

c. Engine Model 6072A, Serial No. 6A20533

					Dry Concentrations Corrected to Wet							Mass Fmission							
												lb/hr				g/bhp/hr			
Date	Time	Mode	hp	rpm	Correction Factor	CO (ppm)	CO_2 (%)	O_2 (%)	NO (ppm)	NO_2 (ppm)	THC (ppm)	CO	NO	NO_2	THC	CO	NO	NO_2	THC
3/7/73	0840	1	22.5	1200	.9778	401	1.91	16.87	293	68	1100	.837	1.007	0.011	1.148	16.8	20.3	.22	23.16
3/7/73	0908	1	21.0	1200	.9783	372	1.86	17.85	274	68	980	.800	0.970	0.011	1.055	17.29	20.97	.24	22.81
3/7/73	0926	2	67.5	1390	.9646	232	3.38	15.55	531	34	1350	.578	2.180	.003	1.686	3.88	14.66	.020	11.34
3/7/73	1005	2	67.5	1390	.9646	233	3.38	15.92	559	29	800	.592	2.335	.003	1.015	3.98	15.82	.020	6.82
3/7/73	1120	3	107	1600	.9593	232	3.93	14.39	696	14	950	.627	3.091	.001	1.283	2.66	13.1	.004	5.44
3/7/73	1143	3	105	1610	.9587	232	4.03	14.38	705	12	750	.616	3.075	.001	0.995	2.66	13.29	.004	4.30
3/7/73	1215	4	142.5	1790	.9508	666	4.85	12.84	332	0	820	2.148	4.417	.000	1.323	6.84	14.08	0	4.21
3/7/73	1240	4	142.5	1790	.9501	608	4.94	13.06	827	0	820	1.929	4.314	.000	1.301	6.14	13.7	0	4.14
3/7/73	1315	5	185	2000	.9407	1072	5.93	11.05	790	0	780	4.548	5.513	.000	1.654	11.16	13.5	0	4.05

TABLE 2. CONCENTRATION EMISSION DATA

Engine Model: Cummins VT-350M   Serial No.: 433539

					Concentrations -- As Measured						
Date	Time	Mode	hp	rpm	CO (ppm)	CO_2 (%)	O_2 (%)	NO (ppm)	NO_2* (ppm)	THC** (ppm)	Notes
2/21	0945	1	95	1500	600	7.5	10.50	860	-	165	
2/21	1015	2	175	2100	680	8.0	9.00	975	-	75	*NO_2 converter not operating properly
2/21	1050	3	225	2350	920	8.5	8.50	1400	-	100	
2/21	1130	4	269	3050	1340	9.0	13.75	1200	-	175	**Leak in heated sampling line to FID
2/21	1135	5	idle	550	350	1.5	19.00	185	-	250	
2/21	1240	6	156	2300	820	8.1	10.12	975	-	75	

TABLE 3. RINGELMANN SMOKE READINGS

Engine Serial Number	rpm	hp	Ringelmann Number
6A60144	1200	20	1.5
	1400	70	2.0
	1600	110	2.0
	1800	150	1.0
6A20533	1200	20	2.0
	1400	70	2.25
	1600	110	1.0
	1800	150	1.0
6A60137	1200	20	1.5
	1400	70	2.0
	1600	110	1.0
	1800	150	2.0

Engine manufacturers are now approaching this problem by redesigning the injector, engine timing, and engine derating in order to meet the California and Federal standards given in Table 4. These standards are weighted numbers obtained when an engine is run through a duty cycle. Since no duty cycle has been established for boat engines, it is not meaningful to apply these figures to marine diesel engines.

TABLE 4. 1974 FEDERAL EXHAUST EMISSION STANDARDS FOR HEAVY-DUTY DIESEL ENGINES

GASEOUS EMISSIONS	
Hydrocarbons + Oxides of Nitrogen	16 gm/bhp-hr
Carbon Monoxide	40 gm/bhp-hr
EXHAUST SMOKE	
20% opacity	Engine acceleration mode
15% opacity	Engine lug-down mode
50% opacity	Peaks in either mode

3. CONCLUSIONS

The engine emission curves (Figure 9) indicate good agreement from engine to engine for levels of CO and NO_x. The maximum deviation from the mean for the three engines at mid-power (100 bhp) for CO and NO_x is less than 13%. The maximum deviation from the mean for THC, however, is 65%. This larger deviation occurs because the THC levels are sensitive to the individual piston-ring and value seating and injector operation. As these engines acquire longer operating hours and the values and ring become uniformly seated, the THC levels from these engines will probably become comparable. The injectors used in these engines are rebuilt to GM standards. No data is available on the emissions levels of THC when rebuilt injectors are used, rather than new ones.

Enough similarity between the engines tested exists to establish baseline data for the assessment of the impact of boats powered by these engines on the Coast Guard fleet emissions. Enough differences between engines exist, however, that each engine must be considered individually in evaluating control methods.

Although the Coast Guard has a well-developed engine-maintenance program, and these engines are generally in better condition than engines found in private truck or bus fleets, or commercial and pleasure boats, it is doubtful that they could meet the more stringent 1974 gaseous emissions standards, particularly with regard to the levels of NO_x and THC. These engines would probably meet the federal smoke standards, but final conclusions can be reached only after quantitative measurements have been made with an opacity smokemeter.

4. RECOMMENDATIONS

From the results to date, the following recommendations can be made:

1. Testing of engines other than the 6-71 should continue, to get baseline data against which future levels can be compared.

2. A rebuilt 6-71 engine should be retrofitted with a GM "Clean Air Kit", and emissions measurements made before and after the change. This engine should be installed in a boat with an otherwise identical rebuilt 6-71. Both engines should be operated over their useful lifetimes, with periodic emissions testing and careful maintenance records, to determine the cost-effectiveness and reliability over time of the retrofit.

3. Smoke measurements should be made with an opacity meter. (This meter is on order; it will be installed and operational before June 30th, 1973.)

4. Used engines should be tested with the dynamometer to determine the relationship between number of hours of engine operation and emissions levels. These data are needed for more exact estimates of the impact of the USCG boat fleet on air quality.

5. Engine-emissions tests must be run with water mixed into the exhaust. The results of last summer's field measurements of the effects of such mixing were inconclusive.

APPENDIX A

NOISE LEVELS FROM GM 6-71 AND GM 6V-53 ENGINES

The noise levels of two GM engines, Models 6-71 and 6V-53, were measured during the emissions runs on the Base Boston dynamometer. The measurements were made with a General Radio Type 1565 sound-level meter. They are given in Table A-1 in terms of dBA (correlation with human ear response) and dBC (flat response). Figure A-1 shows the locations at which the measurements were made with reference to the engine under test. For comparison, Table A-2 lists the maximum daily noise exposure permitted under the Walsh-Healey and National Occupational Health Acts.

TABLE A-1. ENGINE NOISE LEVELS

a. Engine Type 6-71, Serial No. 6A-2053

rpm	hp	Position	dBA	dBC
1000	0	A	90	91
		B	92	93
1200	20	A	100	99
		B	100	102
		C	96	97
		D	96	96
		E	95	95
1400	70	A	100	101
		B	100	101
		C	98	98
		D	96	96
		E	97	98
1600	110	A	102	103
		B	102	103
		C	98	100
		D	97	98
		E	96	97
1800	140	A	103	103
		B	102	103
		C	98	100
		D	98	99
		E	99	99
2000	185	A	103	103
		B	103	103
		C	101	101
		D	95	96
		E	98	98

TABLE A-1. ENGINE NOISE LEVELS (CONT.)

b. Engine Type 6V-53, Serial No. 6D-18675

rpm	hp	Position	dBA	dBC
650	0	A	94	95
		B	94	96
		C	90	92
		D	89	91
		E	89	90
1000	30	A	97	105
		B	98	106
		C	94	100
		D	92	100
		E	92	100
1500	30	A	100	106
		B	101	106
		C	96	100
		D	96	100
		E	95	95
1800	30	A	100	102
		B	103	106
		C	97	99
		D	95	102
		E	98	98
2000	30	A	101	103
		B	102	103
		C	98	99
		D	96	103
		E	99	100
2200	130	A	103	105
		B	104	106
		C	98	100
		D	97	100
		E	99	101

TABLE A-1. ENGINE NOISE LEVELS (CONT.)

b. Engine Type 6V-53, Serial No. 6D-18675

2800	175	A	109	110
		B	109	109
		C	104	104
		D	103	104
		E	104	105

TABLE A-2. PERMISSIBLE NOISE EXPOSURE PER DAY

dBA	Exposure Time (hr)
90	8
95	4
100	2
105	1
110	0.5

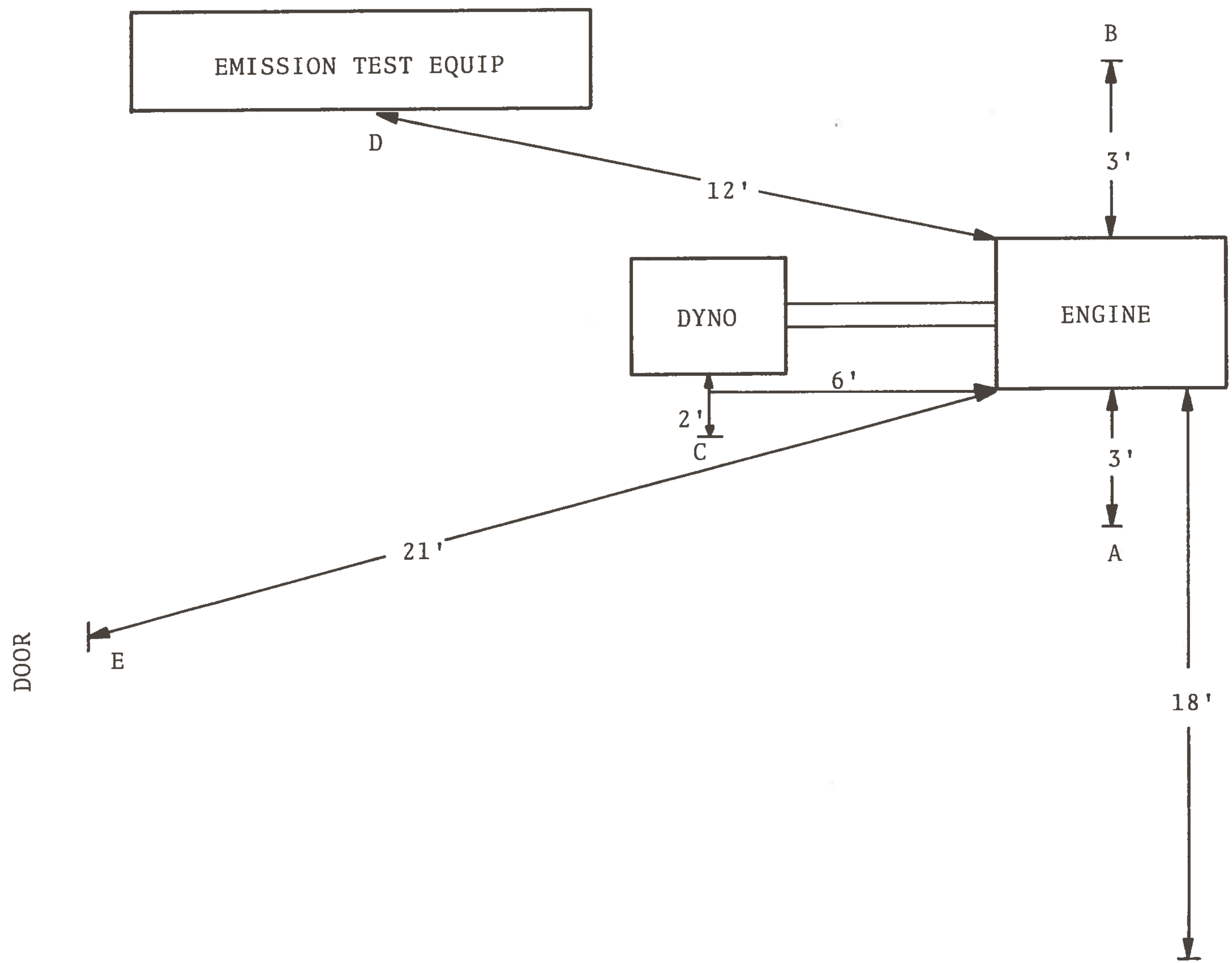

Figure A-1. Location of Noise-Level Readings

REFERENCES

1. R.A. Walter, A.J. Broderick, J.C. Sturm and E.C. Klaubert, USCG Pollution Abatement Program: A Preliminary Study of Vessel and Boat Emissions, U.S. Department of Transportation, DOT-TSC-USCG-72-3, November 1971.

2. Anthony F. Souza, Final Report: A Study of Stack Emissions from Coast Guard Cutters, Scott Research Laboratories, Report No. CG-D-13-73, Sept. 1973.

3. SAE, Procedure for the Continuous Sampling and Measurement of Gaseous Emissions from Aircraft Turbine Engines, Society of Automotive Engineers, Inc., New York, N.Y., ARP 1256, October 1971.

4. R.J. Hames, D.F. Merrion, and H.S. Ford, Some Effects of Fuel Injection System Parameters on Diesel Exhaust Emissions, Society of Automotive Engineers, 710671, 1971.