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FIELD TESTS OF IN-SERVICE MODIFICATIONS TO IMPROVE PERFORMANCE --ETC(U)
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FIELD TESTS OF IN-SERVICE MODIFICATIONS TO IMPROVE PERFORMANCE OF AN ICEBREAKER MAIN DIESEL ENGINE

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AUGUST 1977

FINAL REPORT

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16. Abstract

Field tests of in-service modifications to improve engine efficiency and lower the emissions were performed on the #3 main diesel engine of the USCGC Mackinaw (WAGB-83). This engine is a model 38D8-1/8 manufactured by Colt Industries, Fairbanks Morse Engine Division, and is rated for 2000 hp at 810 rpm. Baseline and modified engine tests were performed while the ship engaged in routine maneuvers of engine start, warm-up, docking, undocking and steady-steaming. The measurements performed included fuel consumption, smoke carbon monoxide (CO), carbon dioxide (CO_2), oxides of nitrogen (NO_x), total hydrocarbons (THC), oxygen (O_2), engine speed and load, as well as important engine temperatures and pressures.

The engine modifications were newer style pintle type fuel injector nozzles, shimmed injection pumps and advanced injection timing. These modifications decreased fuel consumption 1% to 3% depending on speed and load, reduced CO and THC up to 43% and 88% respectively and increased NO_x up to 38%. Smoke emissions decreased 50% at low-load engine conditions and 5% at high-loads.

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PREFACE

As part of a Coast Guard program to improve efficiency and reduce the emissions of diesel engines, field tests of proposed modifications to the FM 3808 1/8 engine were performed on the USCGC Mackinaw (WAGB-83). Fuel economy and emissions of an unmodified and modified engine were measured while the ship performed routine maneuvers.

This work was performed under contract to the Department of Transportation, Transportation Systems Center for the U.S. Coast Guard, Office of Research and Development. The Coast Guard project officers for R&D and Engineering were Lcdr. J. Sherrard, Lt. T Marchevko and Lt. R. Gulick. The TSC technical monitor was R. Walter. The efforts of Scott Environmental Technology Inc., and the crew of the USCGC Mackinaw especially Captain Garnett, CO, and Lcdr. Scott Duncan, EO, are greatfully acknowledged.

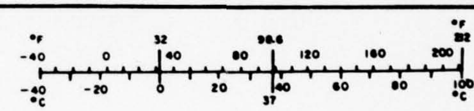
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04		in
cm	centimeters	0.4		in
m	meters	3.3		ft
m	meters	1.1		yd
km	kilometers	0.6		mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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LIST OF SYMBOLS

AIDC	After Inner Dead Center
AIDC LC	After Inner Dead Center of Lower Crankshaft
Alt. Resh.	Atlantic Research
ARC	Atlantic Research Corporation
@	At
Bl.	Blower
B.M.C.V.	Before Minimum Clearance Volume
BMEP	Brake Mean Effective Pressure
BMV	Before Minimum Volume
BSFC	Brake Specific Fuel Consumption
CO	Carbon Monoxide
CO_2	Carbon Dioxide
Cyl.	Cylinder
Deg.	Degrees
°F	Degrees Fahrenheit
DOT	Department of Transportation
Eng.	Engine
F.I.D.	Flame Ionization Detector
FM	Fairbanks Morse
g/bhp-hr	Grams Per Brake Horsepower Hour
HC	Hydrocarbon
H.C.	High Cam
in./hr.	Inches Per Hour
Incr.	Increased

Indiv.	Individual
INJ.	Injection
J.W. Temp.	Jacket Water Temperature
KW	Kilowatts
Ltd.	Limited
L.O. Temp.	Lube Oil Temperature
MAX.	Maximum
Min.	Minute
min./in.	Minutes Per Inch
Mod.	Modified
M.S.A.	Mine Safety Appliances Company
N.D.I.R.	Non-Dispersive Infrared
[illegible]	Number
[illegible]	Nitrogen Oxide
O_2	Oxygen
P.C.	Port Closure
%	Percent
#/bhp-hr	Pounds Per Brake Horsepower Hour
#/hr	Pounds Per Hour
P.O.	Port Opening
PPM	Parts Per Million
PSI	Pounds Per Square Inch
R. Bosch	Robert Bosch
rpm	Revolutions Per Minute
RTV	Room Temperature Volcanizing
SRI	Southwest Research Institute
TECO	Thermo Electron Corporation

Temp.	Temperature
THC	Total Hydrocarbons
TSC	Transportation Systems Center
USPHS	United States Public Health Service
V.B.	Variable Beginning
V.E	Variable Ending

I. SUMMARY AND CONCLUSIONS

The objective of these tests was to verify, through actual field tests, the effectiveness of proposed engine modifications to improve engine efficiency and reduce exhaust emissions of the 38D8-1/8 Fairbanks-Morse opposed-piston engine. These modifications, which had previously been tested in the laboratory, consisted of newer style pintle-type nozzles, shimmed injection pumps and advanced injection timing.

These tests were conducted on the #3 Main Diesel Engine of the USCGC Mackinaw (WAGB-83). Baseline (unmodified) and modified tests were completed while the ship performed routine maneuvers of engine start-up, idle, undocking, docking, and steady-steaming. Gaseous and smoke emissions, fuel consumption, and other important engine parameters were measured as a function of engine speed and load.

Based upon the results of these tests, we have reached the following conclusions:

-1- Gaseous emissions of carbon monoxide (CO) and total hydrocarbons (THC) were reduced up to 43% and 88% respectively with the modified engine. Oxides of nitrogen (NOx) increased up to 38% after the modifications.

-2- Smoke emissions, already low, decreased 50% at low loads and 5% at high loads with no significant change through the midpower ranges.

-3- Fuel consumption with the modified engine decreased 1% to 3% depending on speed and load conditions.

-4- For the Mackinaw, these fuel economy improvements would save $1,050 to $3,150 per year for all main engines based on a main engine fuel usage of 300,000 gallons per year at 35¢ per gallon.

The Glacier's engines would also be expected to show an improvement in fuel consumption after modification. However, since the Glacier's engines are configured slightly different from the Mackinaw's, the magnitude of the savings cannot be demonstrated from the tests reported herein.

-5- It has been previously demonstrated (Appendix A) that the pintle nozzle will increase cylinder liner life up to 25% because of the decreased "washing" of lubricating oil from the liner wall with excess unburned fuel. Fuel oil dilution of the lubricating oil should also be significantly reduced.

-6- The pintle nozzle maintenance costs are lower because of reduced parts costs ($11.80 vs $78.50 for the needle and sleeve plus gaskets of the old style nozzle) and 25% less rebuilding time.

-7- The lower smoke (particulate) and THC emissions will decrease the build-up of stack deposits resulting in fewer stack fires.

-8- The engine jacket water and lube oil keep warm temperatures are important and were considered adequate on the test engine. The higher temperatures help reduce white smoke at start-up and during warm up idle. High keep warm temperatures will reduce total engine smoke emission during start-up and initial engine loading. Engine warm up idle of more than several minutes serves no useful purpose other than convenience when the keep warm temperatures are adequate.

-9- Although no cost savings can be placed on the air quality improvements, the pintle nozzles will reduce white smoke at low load operations and black smoke during load acceptance. This will reduce the likelihood of smoke problems in air pollution-sensitive areas.

-10- The costs for modification of a ten-cylinder engine are $6,111.32 for hardware, tools and spare parts. If the complete modifications were performed by FM personnel, it would take them approximately 10 man days at a cost of $250.00 per day or $2,500.00 per engine. These figures are as of the date of this report.

-11- All gaseous emission measurement instruments performed nominally.

-12- Accurate smoke data were difficult to obtain because of smoke interference from other stacks and thermal-distortions of the smokemeters.

-13- The volumetric (3.5 gallons) fuel measuring device was adequate for these tests, but required long measuring times at low-speed and load conditions.

-14- The engine load and speed test conditions were difficult to reproduce and hold steady over the time required for data collection, especially at the low-speed and load conditions that required long fuel-flow sampling times.

2. RECOMMENDATIONS

The following recommendations are made:

The 38D8-1/8 engines in the fleet be modified with the pintle nozzle, injector pump shims, and changed injection timing. These modifications could be accomplished as part of normal engine maintenance. (However, this will require ships to maintain duplicate stocks of injectors until all engines are modified.) The shims and timing changes apply only to engines having the .625" lift camshaft.

Improved instrumentation should be developed to measure and record engine speed, load and instantaneous fuel consumption.

A follow-up effort with the Mackinaw should be maintained to assure the modified engine is performing adequately and determine any long term improvements in smoke, injector maintenance and lubricating oil condition.

3. INTRODUCTION

The FM 38D8-1/8 engine in various configurations provides main propulsion on some icebreakers and coastal buoy-tenders. This engine has been identified as emitting, in some instances, unacceptably high levels of white and black smoke. Prior to the tests reported here, laboratory tests of a ten cylinder engine (2000 hp at 810 rpm) configured similar to an icebreaker engine, were conducted at Colt Industries. These tests identified methods of controlling the smoke emissions while improving engine efficiency (Ref. 1). From the results of these laboratory tests, certain engine modifications were selected for field testing to verify their effectiveness under actual operating conditions. The USCGC Mackinaw (WAGB-83) was selected as the test cutter. Baseline (unmodified) and modified tests were performed on the #3 main diesel engine while the ship was performing routine operations of start-up, idle, undocking, docking, and steady-steaming.

4. EXPERIMENTAL TESTS

Carbon monoxide (CO), carbon dioxide (CO_2), total hydrocarbons (THC), oxides of nitrogen (NOx) and oxygen (O_2) as well as smoke opacity, were measured in the exhaust of the USCGC Mackinaw #3 main diesel engine. Fuel consumption was determined by timing the usage of a known volume of fuel. The ship motor room power meter (generator KW) and tachometer (engine rpm) were used for logging engine load and speed. Engine speed was verified by hand-tachometer in the engine room. Other logged engine room data included; jacket water and scavenging air temperature and pressure, exhaust temperatures (individual cylinder and combined), and injection pumps rack-readings.

4.1 EXHAUST GAS EMISSIONS MEASUREMENT

The emissions measurements performed by Scott Environmental Technology Inc. were continuous in real-time. The instrumentation for these measurements was located in the ship's log office (Fig. 1). An exhaust gas sample was drawn from the #3 engine stack at a point approximately ten feet above the main deck (Fig. 2). A detailed description of the exhaust gas analysis system and associated instrumentation is given in Appendix B. Instrument readouts were on strip-chart recorders also located in the log office.

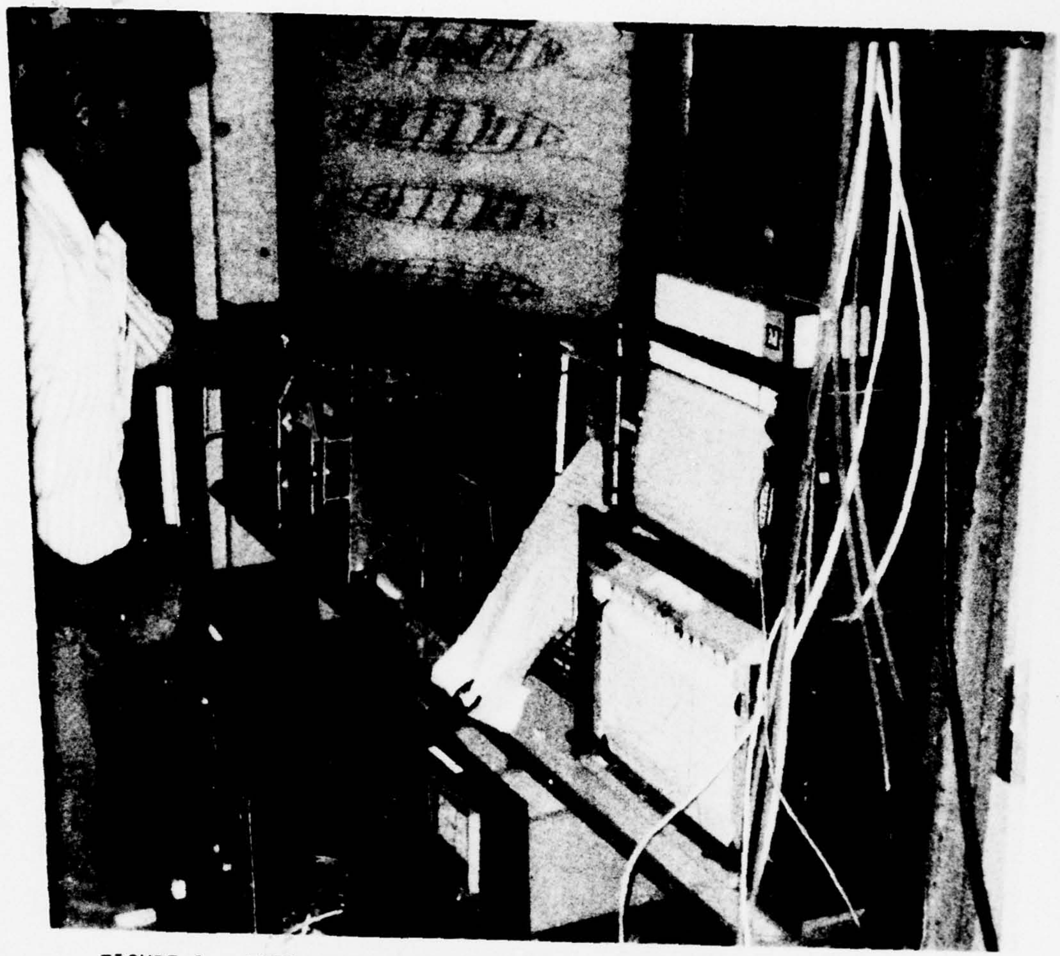

FIGURE 1. EMISSIONS MEASUREMENTS INSTRUMENTATION

FIGURE 2. EXHAUST GAS SAMPLE INSTRUMENTATION

4.2 SMOKE MEASUREMENTS

Two smoke meters were used for these tests. The first, the USPHS smoke meter, attaches to the top of the stack and is the recommended EPA diesel smoke measuring device. The second, an Atlantic Research Inc. in-line opacity meter measures the smoke density in the stack. Both of these meters work on the principle that light can be attenuated due to the absorption and scattering of the light by particulate matter in an optical medium such as stack gas. These meters have a light source, appropriate optics and a photo-detector. The stack gas is made to flow between the light source and detector. The major difference between the two smoke meters used here is that the USPHS meter has an incandescent bulb for a light source whereas the Atlantic meter uses a light-emitting diode (LED) for its source.

In order to adapt these two meters to the #3 main engine, a stack extension was fabricated and bolted to the top of the stack (Appendix C). This extension served two purposes:

-1- provided a housing for the in-line meter;

-2- raised the level of the top-of-the-stack meter (USPHS) so that smoke from other engines would not drift through the USPHS smoke meter optical path and give erroneous readings

The smoke meter and extension are pictured in Figures 3 and 4. The controls for these meters were located in the passageway between the up-stack area and the log office (Fig. 5). Readout was by strip chart recorder also located in the log office. A sample strip chart recording is included in Appendix C. The smoke readings are in % opacity (% opacity = 100% - % transmittance).

4.3 FUEL-FLOW MEASUREMENT

The fuel-flow measuring device fabricated for these tests held 25 pounds of fuel (Fig. 6). Fuel consumption was measured with this device by timing the usage of the 25 pounds. In operation, when the engine was stabilized at the test speed and load, valves were turned such that fuel usage was from the 25 pound tank. Sight tubes with reference marks were located at the top and bottom of the fuel-flow measuring device (25 pounds between marks). A stop-watch was started and stopped as the fuel level passed these reference marks.

4.4 OTHER MEASUREMENTS

Previously mentioned measurements (Section 4) of engine speed, load, and engine operating conditions were hand-recorded on sheets by test personnel in the motor room and engine room (Appendix D). These measurements were recorded as a function of time-of-day for later correlation to other experimental data.

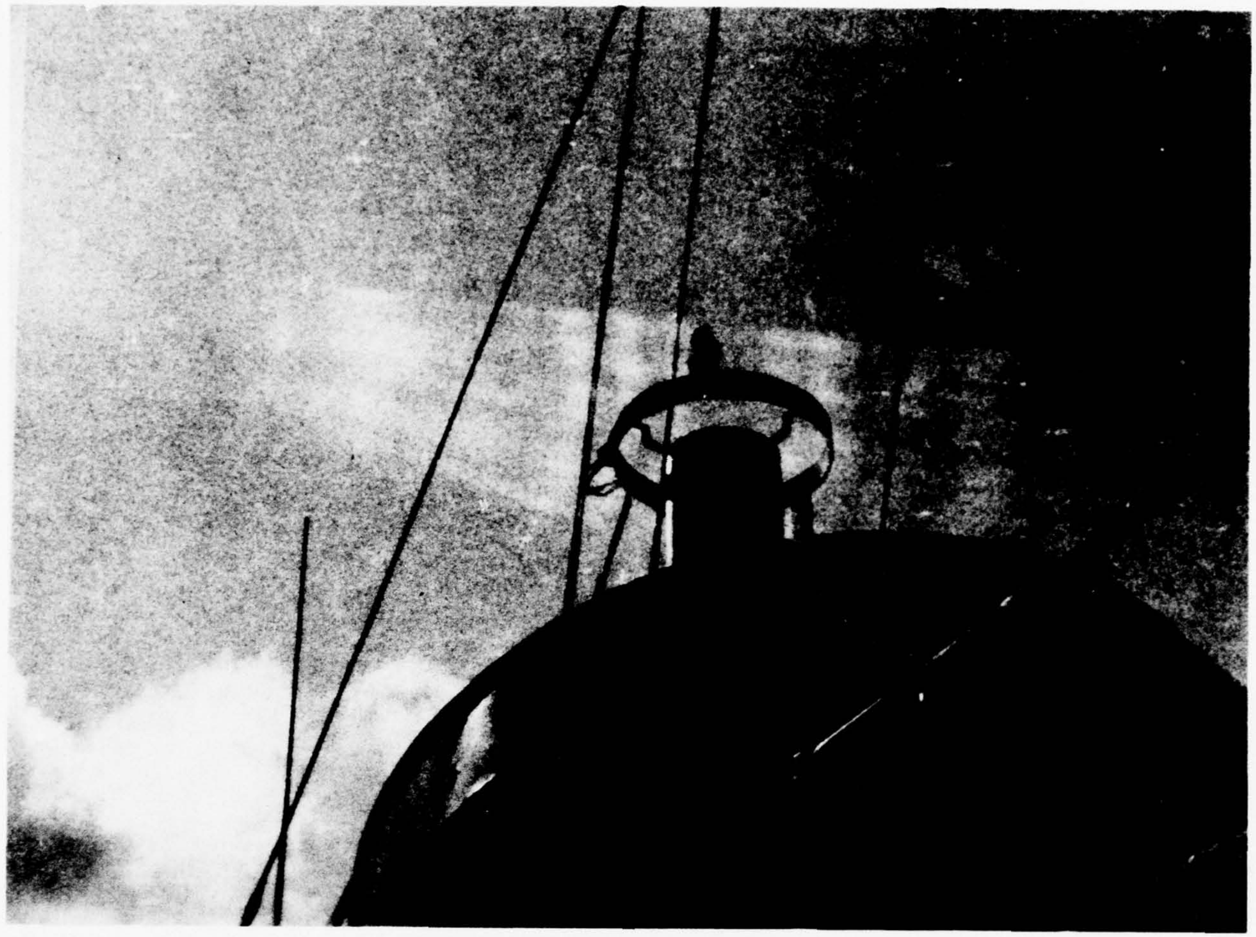

FIGURE 3. OPACITY METER

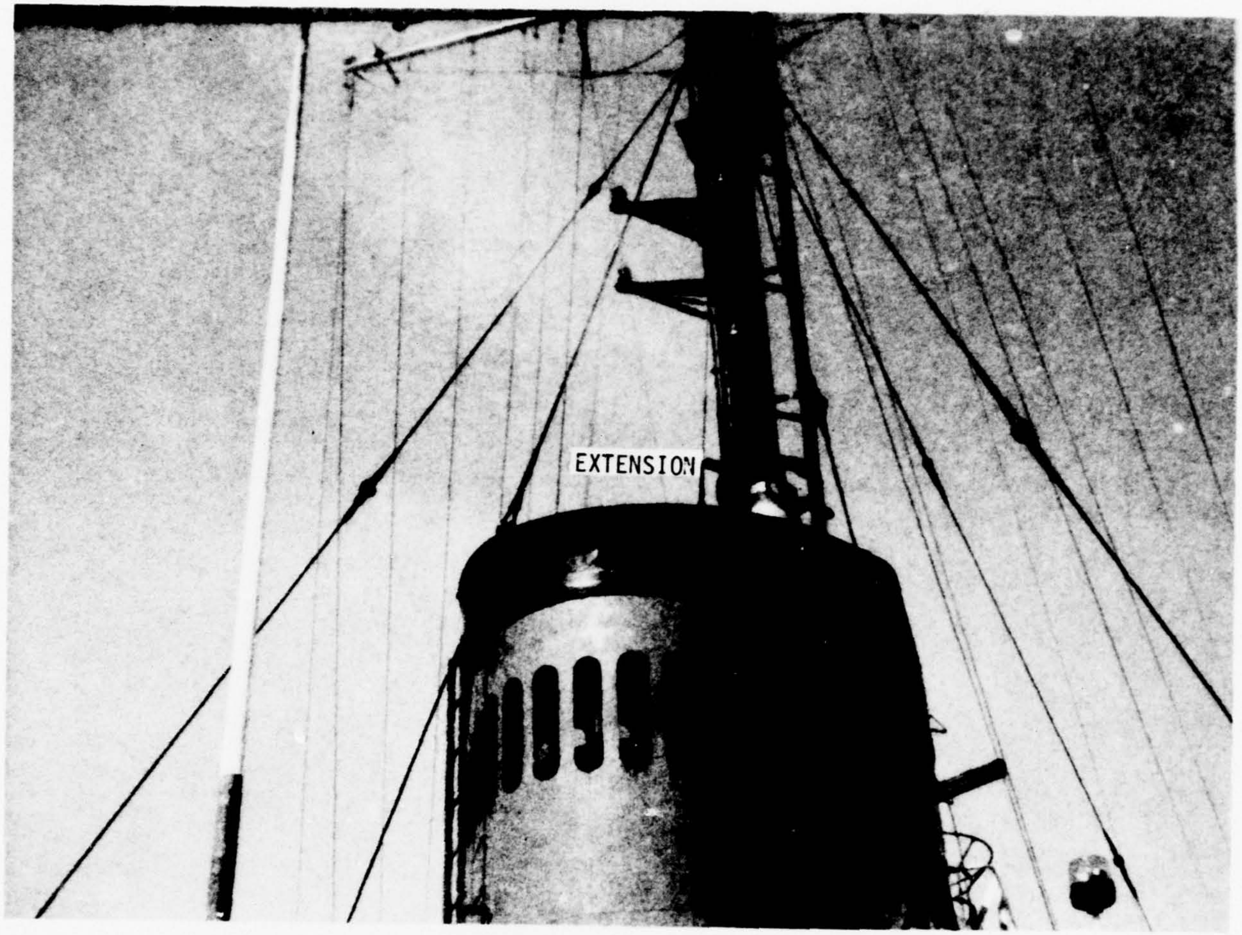

FIGURE 4. OPACITY METER - EXTENSION

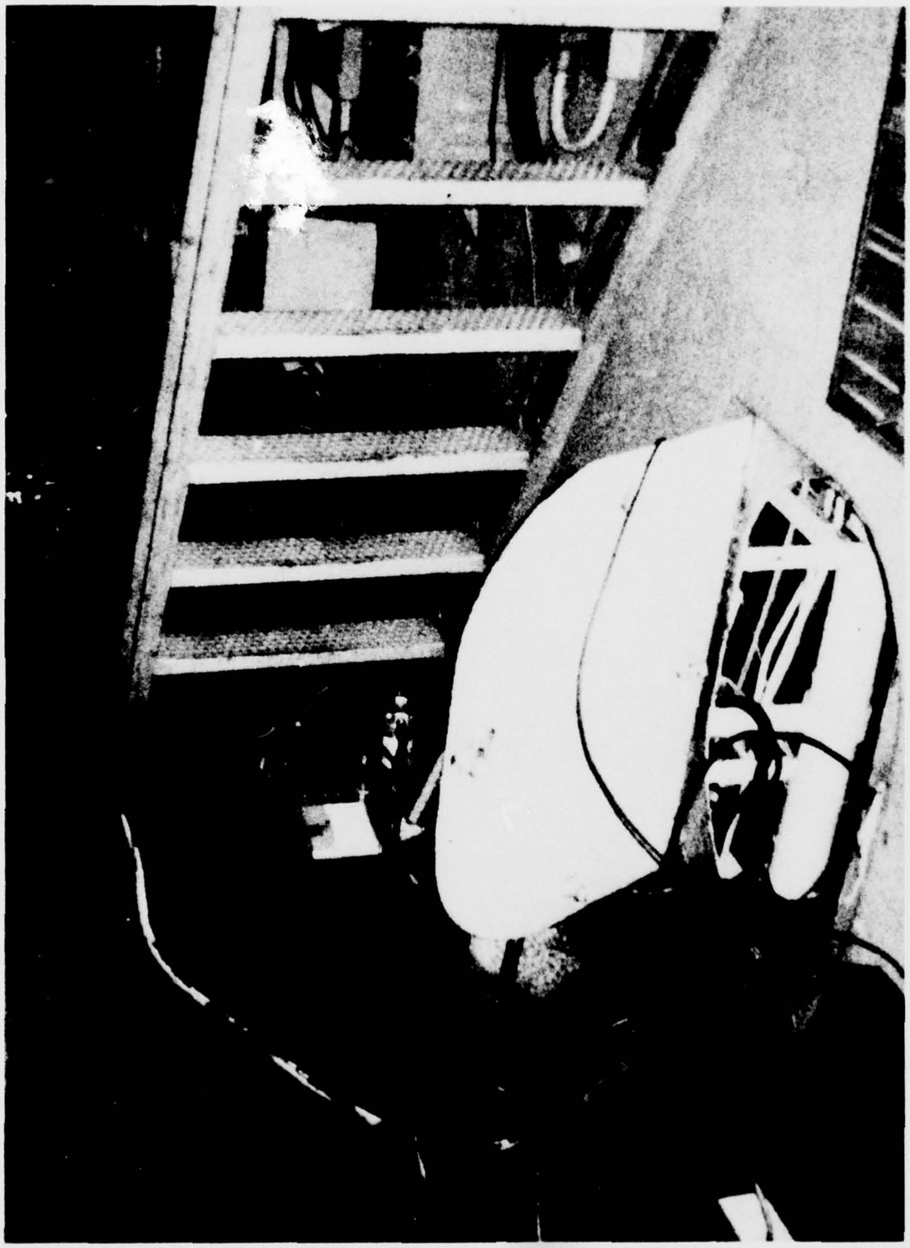

FIGURE 5. SMOKE METER CONTROLS

FIGURE 6. FUEL-FLOW MEASURING DEVICE

5. TEST RESULTS

Baseline unmodified engine tests were performed during two cruises on August 25 and August 26, 1976. The engine was modified from August 27th through August 30th. Modified engine tests were conducted on September 1 and 2. For all engine tests, the instrumentation was warmed-up for approximately one hour before engine light-off. (Some instrumentation was left on continuously). Calibration gases were used to periodically calibrate the gaseous instrumentation. The USPHS and in-line smoke meter were zeroed and full-scaled before each test run. In addition, the USPHS smoke meter was calibrated with neutral density filters after its installation. (The in-line meter was not accessible for a test with the filters). Each engine speed and load condition was maintained a sufficient time to allow engine operating conditions to stabilize and a representative record of emissions to be obtained. The slower fuel-flow readings determined the time spent at each speed/load test point. The readings in the motor room of speed and load were at five minute intervals or when speed and load changed. (During docking and undocking, rapid changes in speed and load precluded reliable engine data and any fuel measurements.) Detailed test procedures can be found in Appendix E.

5.1 BASELINE ENGINE TEST

The baseline engine tests were performed on August 25 and August 26. The #3 main engine used for the tests was reported by the crew to be in the best operating condition of all the main engines. This engine had acquired 980 hours of operating time since overhaul the previous summer. The operating condition was verified by the relatively low smoke readings. No changes or adjustments were made to the engine for the baseline tests, aside from adding the fuel measuring device and stack extension. The unmodified engine condition and settings were as follows:

- Engine: Number 3 main diesel engine S/N 833861 per contract TCG24101, right hand engine with right hand rotation, rated 2000 horsepower at 810 rpm, built in 1943 by Fairbanks-Morse.
- Engine had operated 25,020 hours.
- The engine had acquired 980 hours since the last overhaul. This overhaul consisted of replacing compression rings, all main bearings, one cylinder liner and connecting rod, two pistons, the fuel and oil pump, governor, and six bearing caps and rebuilding injection nozzles.
- Injection timing was found to be different on the two sides of the engine at 31.3 and 33.7 degrees after inner dead center of the lower crankshaft.
- Lube oil consumption since overhaul was 1345 gallons during 980 hours. The majority of this oil was believed lost by leakage in the engine external oil system.
- Engine keep warm temperatures:

  Jacket water - 160°F
  Lubricating oil - 120°F

The unmodified engine power components of this engine consisted of:

- Blower-scavenged engine cylinder liners.
- Mexican-hat pistons with 13.6:1 compression ratio at a cranklead of 12 degrees.
- Camshaft with .625 inch lift.
- Injection pumps with 1/2 inch plunger having variable ending helixes.
- FM 3-hole injection nozzles with .0225 inch diameter orifices.
- Blower with 27 inch long rotors.
- Blower drive gear ratio of 2.0125:1.
- Compression rings with crown face (FM part No. 16704845).

5.2 ENGINE MODIFICATION

Engine modifications were made during August 27th through August 30th with the help of the Mackinaw crew and three service repairmen from Fairbanks-Morse.

The FM 3-hole injection nozzles and fuel oil drain headers were removed from the engine and pintle 10° gasketless type nozzles (P/N 16705663) along with mounting hardware (catalog No. 201.14) and new fuel drain headers were installed in the engine. All fuel injection pumps were removed from the engine and shimmed to make the barrel .03 inch above the plunger height. The injection timing was checked and set to give high-cam 27 degrees after inner dead center of the lower crank. Aside from these changes all other engine operating conditions and settings were as for the unmodified engine.

The pintle nozzle has historically and during the laboratory tests (Ref. 1) demonstrated better fuel injection characteristics, especially at low speed and load conditions. This nozzle minimizes post-injection fuel dribble that contributes to high hydrocarbon and smoke levels. This unburned fuel can also dilute the lube oil. The laboratory tests also indicated that the shimmed injection pumps and adjusted injection timing increased the rate of fuel injection (decreased fuel injection time) and gave better performance in variable speed, variable torque applications.

5.3 MODIFIED ENGINE TESTS

Modified engine tests were performed during two cruises on September 1 and 2, 1976. All test instrumentation and procedures were the same as the unmodified tests.

6. TEST RESULTS AND DISCUSSION

Gaseous emissions concentrations of CO, CO_2, O_2, NOx and THC at the various test points along with the printout data from the emissions computations for each point of the four test runs are in Appendix F. Of these data, the most accurate are the emissions concentrations and the engine rpm. The gaseous emissions readings and smoke readings in Tables F-1 through F-4 started after the clock time with the test point number. The engine rpm readings are within ± 2 percent and, therefore, an air flow computation was used to determine the accuracy of the engine load and/or fuel flow. The air flow was calculated by using the percent of carbon dioxide and oxygen in the exhaust gas in combination with the fuel-flow. If this computed air flow agreed with the engine-driven scavenging air blower capacity at the measured engine rpm, the data was considered relatively accurate. When the air flow data did not agree, the load and/or fuel flow were adjusted. The adjustment was determined by the measured percent carbon dioxide at that test point compared to other test points that did cross-check within ± 2.5 percent.

The specific emissions (Tables F-5 to F-8) are reported in grams per kilowatt hour as the generator efficiency curves at various shaft speeds are not known. Since test results of two engine configurations are being compared to each other and the loading equipment was the same for both test configurations, leaving the engine load in kilowatts and emissions in gm/kw-hr is convenient and most accurate. However, the computer format used for the data reduction in these tables is based on engine brake horsepower. In these tables where brake horsepower occurs, kilowatts are to be substituted. The calculated BMEP in the Appendix F must be multiplied by the horsepower to kilowatt conversion factor of 1.341 and divided by the generator efficiency, if known, at the generator output and speed. For instance, at a load of 1060 kw, 735 rpm and an assumed generator efficiency of .943, the bmep would be (55.07 x 1.341) ÷ .943 = 78.31 psi. The percent torque then would be 78.31 psi divided by the engine rated bmep of 84.8 psi, which equals 92.3%.

The gaseous emissions of CO, THC and NOx are shown in plotted form (Figures 7, 8 and 9), in grams per kilowatt hour versus engine generator load in kilowatts for the modified and unmodified engine. The percent change and mass change in emissions at no load and each 200 kilowatt increment are tabulated below.

TABLE 1

EXHAUST EMISSIONS CO, THC AND NO_x
% CHANGE AND MASS CHANGE FROM UNMODIFIED ENGINE VERSUS
MODIFIED ENGINE WITH PINTLE NOZZLES

Kw	0		200		400		600		800		1000	
GAS	%	gm/hr	%	gm/hr	%	gm/hr	%	gm/hr	%	gm/hr	%	gm/hr
CO	-43	-1560	-38	-600	-25	-280	-15	-150	0		0	
THC	-88	-4054	-75	-1280	-83	-1200	-72	-960	-66	-960	-58	-960
NOx	+21	+213	+38	+1500	+17	+1480	+8.5	+1080	+8.9	+1360	+8.6	+1500

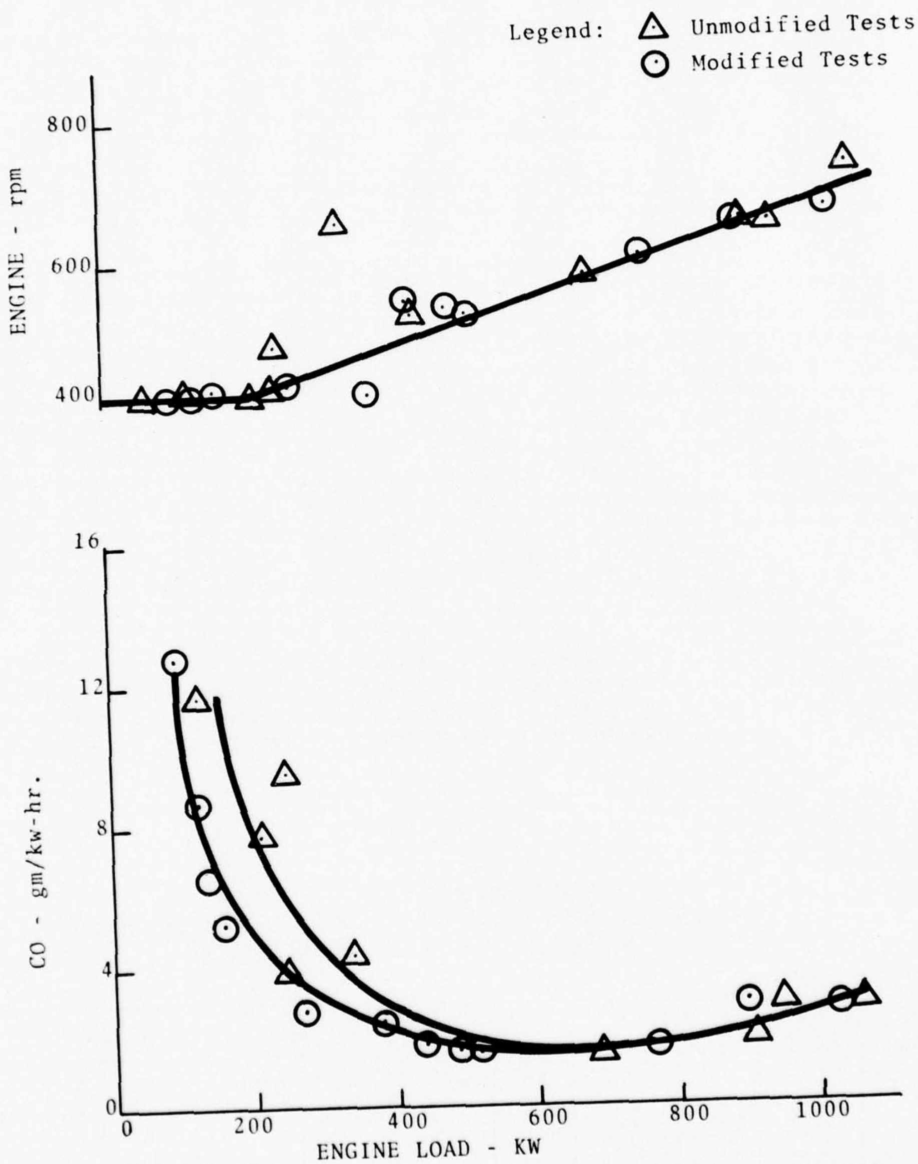

FIGURE 7. DIESEL ENGINE CARBON MONOXIDE EMISSIONS - USCG MACKINAW (WAGB-83)

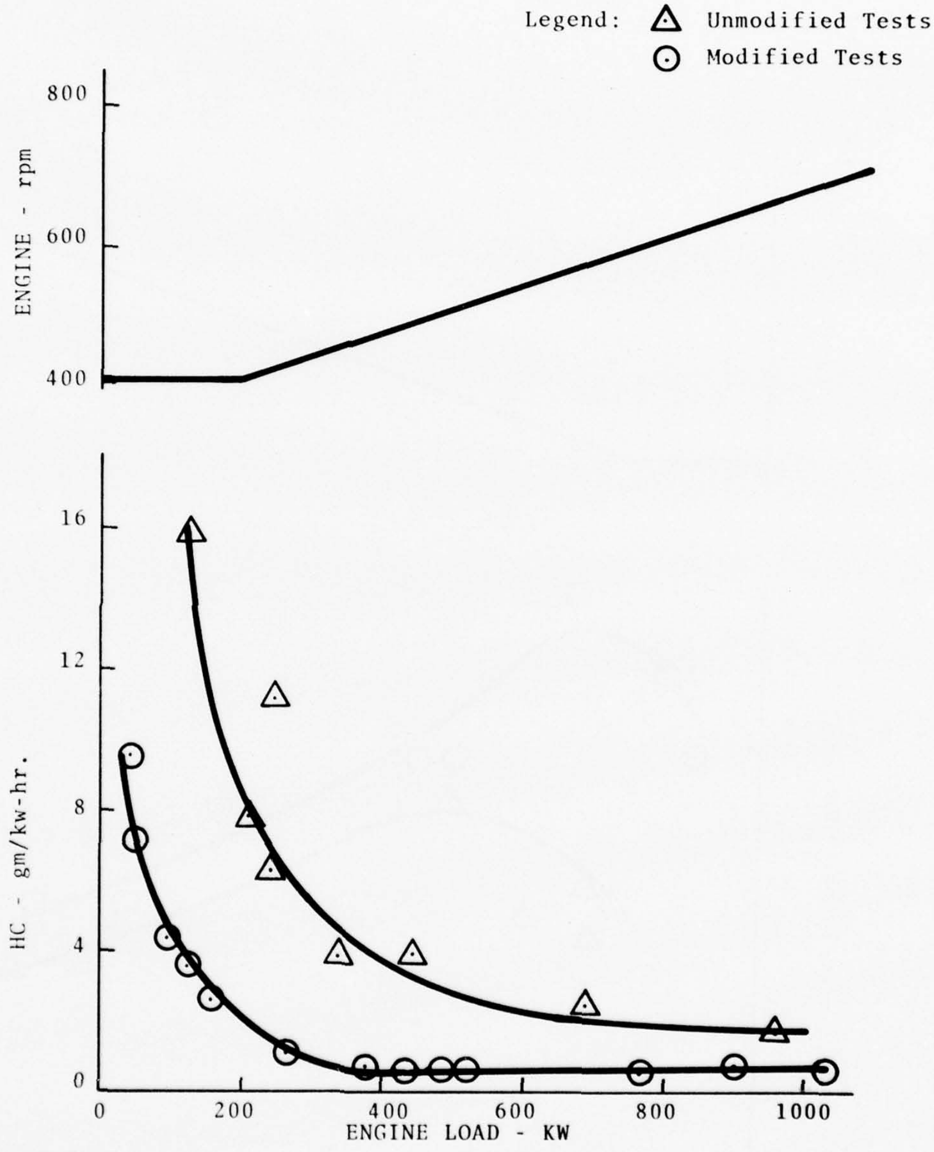

FIGURE 8. DIESEL ENGINE HYDROCARBON EMISSIONS - USCG MACKINAW (WAGB-83)

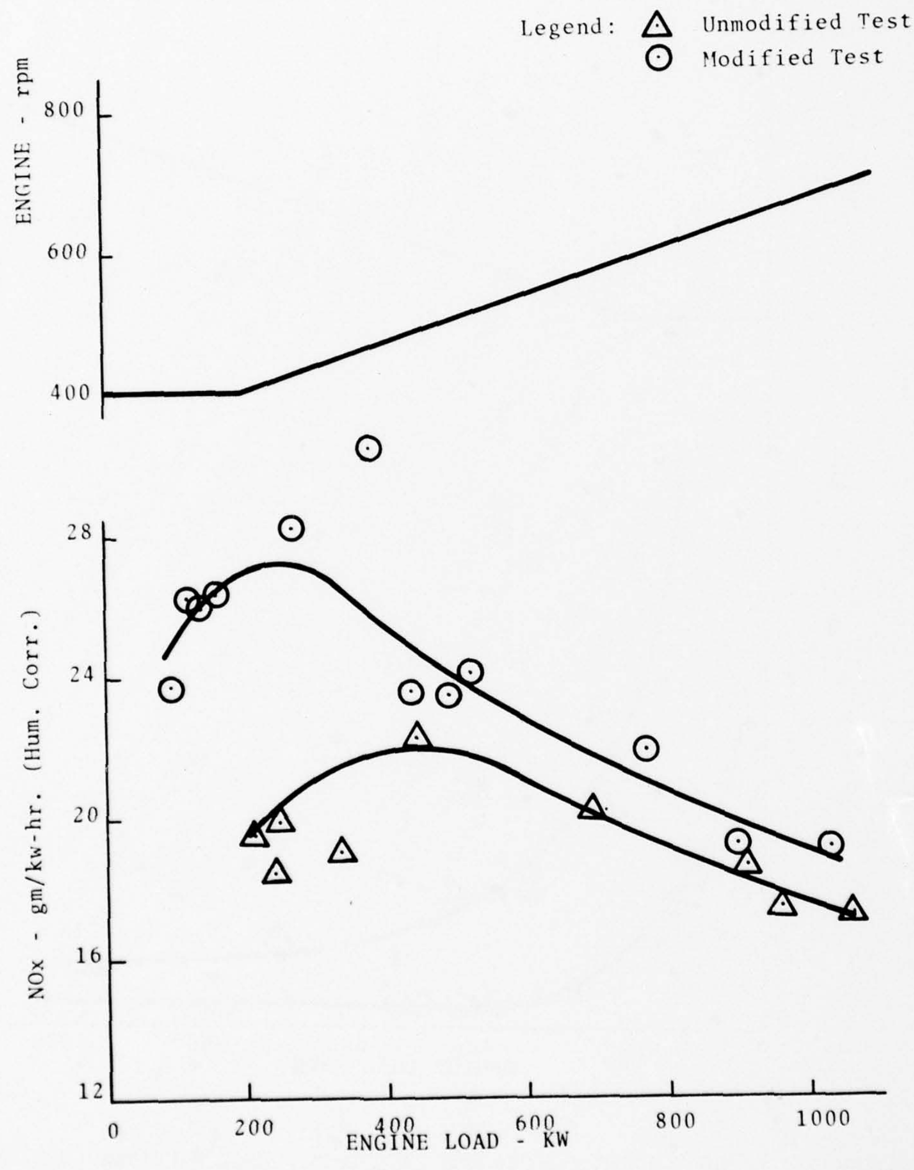

FIGURE 9. DIESEL ENGINE NITROGEN OXIDE EMISSIONS - USCG MACKINAW (WAGB-83)

The modified engine shows a significant reduction of CO at the lower engine loads and speeds, Figure 7. This reduction is due to the better atomization of the fuel oil with the pintle nozzle and the faster rate of injection at the beginning of injection, particularly at low engine speeds. The reduction in CO at no load, idle speed was from 3610 to 2050 grams per hour.

The THC emissions show a drastic improvement throughout the engine load and speed range with the modified engine, Figure 8. The change in THC varied from an 8 fold improvement at idle-no load, to a 3 fold improvement at 1000 kilowatts. This is a reduction of over 4000 grams per hour (8.8 lbs/hrs.) at no load and 960 grams per hour (2.1 lbs/hr.) at 1000 kilowatt load. The reduction can be attributed to the faster rate of injection, better fuel atomization and absence of injection nozzle dribble.

At the higher loads the THC with the pintle nozzles is the same as that obtained during simulated laboratory test (Ref. 1). The .6 gm/kw-hour is about .4 gm/bhp-hr. The specific THC emissions start increasing with reduced load below 40 psi bmep, the same as the lab test. Above 40 psi bmep, the specific emissions of THC are flat with the pintle nozzles.

The NOx specific emissions are higher for all comparable test points as shown in Figure 9. The higher NOx readings are generally indicative of a better performing engine. The faster rate of injection at pump port-closure shows up as a larger increase in NOx at low engine speed and loads. The laboratory tests showed a 10% to 30% increase in NOx with a constant speed, variable load test. Part of the increase reported here may be due to the unmodified engine injection timing being 2.7 degrees late on one side of the engine (33.7° instead of 31°).

6.1 SMOKE MEASUREMENTS

The exhaust smoke measurement during the test are shown in Appendix D. The smoke numbers on the computer printout sheets are % opacity. Figure 10 is a comparative plot of the smoke versus kilowatts recorded by USPHS smoke meter during the four test runs. The in-line meter results were not reliable because of thermal distortions. The idle and light load is about one-half with the modified engine, while no significant difference was noted above 400 kw load. It should be pointed out that under some circumstances the measuring arrangements allowed smoke from other engine stacks to pass through the opacity rings. The stack was 16 inches in diameter while the opacity ring was 30 inches in diameter. Therefore, the smoke reading may be lower than recorded. It is doubtful that the smoke readings will exceed 10% opacity, except following load changes and overloaded conditions. The ideal condition for collecting smoke data would be all engines stopped except the test unit. (However, this ideal condition would not be representative of actual ship operation.) Laboratory tests gave full torque, variable speed smoke readings of less than 7% opacity.

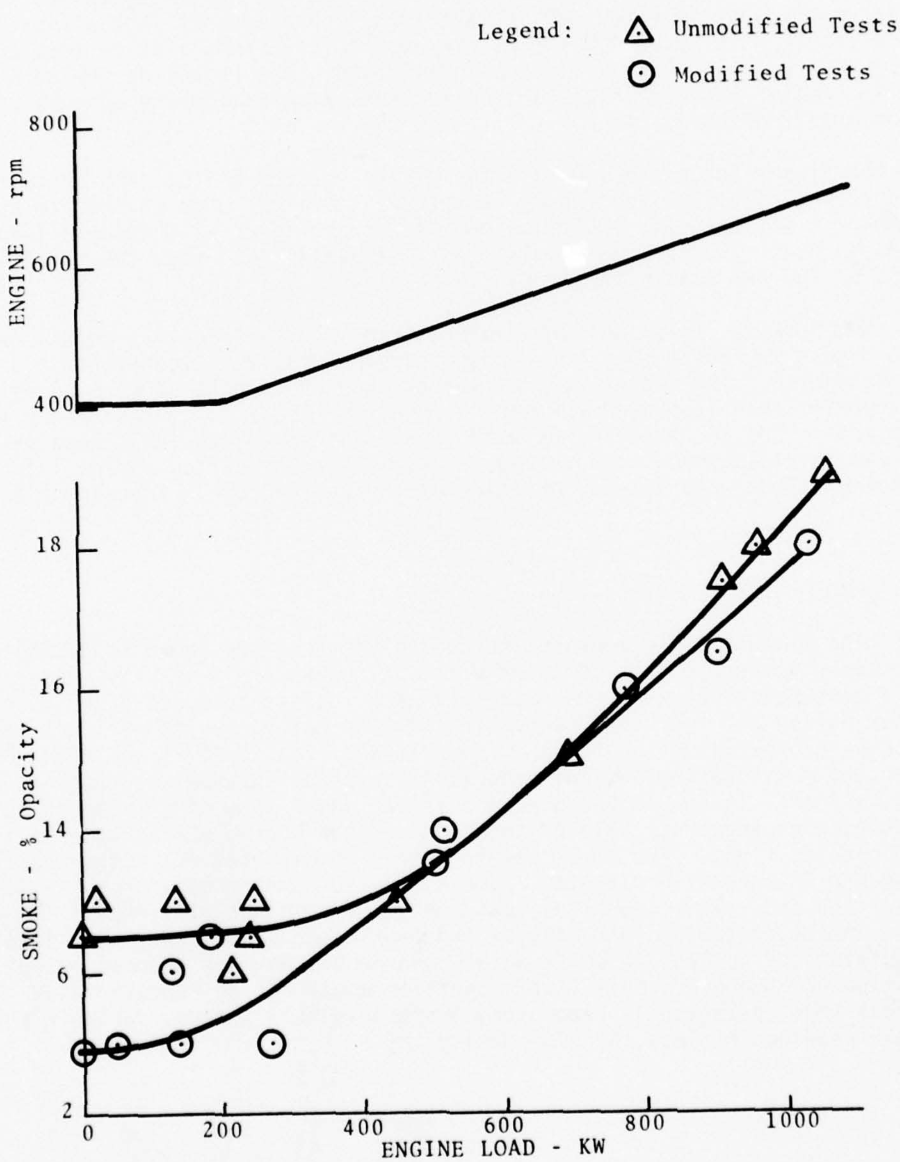

FIGURE 10. DIESEL ENGINE SMOKE EMISSIONS USCG MACKINAW (WAGB-83)

It was noted that the stack turned blue as the load increased, indicating lube oil vapor. This vapor could be coming from the engine or from the heating of the long exhaust stack. Every attempt should be made to determine exact lube oil consumption rates of the various engines. One gallon of oil should be sufficient for 2 to 4 hours of operation. If more than one gallon of oil per 2 hours is being used by the engine, we suspect that one of the following is at fault.

- Worn oil rings or flat-faced type compression rings. Replace with latest style barrel face rings.
- Oil leakage past the upper liner to cylinder block fit. Replace liner to block seal ring.
- Tappet oil drain lines plugged or broken allowing oil to drain into fuel oil or get in engine air manifold.
- External oil leaks.
- Start and stop operation where lube oil leaks past upper pistons. Bar the engine over with air five minutes after each engine shutdown.

The subject test engine had lube oil leaking past the upper liner to block seals. Early FM engines had no seal ring between the upper cylinder liner and block fit. Later engines had an "O" ring which hardened with time. Present production engines have an improved "O" ring compound. This "O" ring is furnished for all service orders of liner to block "O" ring seals. The latest "O" ring is light in color while the earlier ring, which should not be used, is black.

6.2 FUEL CONSUMPTION MEASUREMENTS

The test results gave an improvement in fuel consumption of 1 to 3 percent with the modified engine as shown in Figure 11. These results are as expected considering the increase in the NOx gaseous emissions. Part of the improvement may be due to the late injection timing of the unmodified engine mentioned previously. The laboratory simulated engine (constant speed, variable load) tests gave fuel consumption improvements of less than 1% when all adjustments and settings were as required.

We noticed a reduction in injection pump racks for the same engine load on the modified engine. This is mainly due to the decrease in injection pressures associated with the pintle type nozzles as compared to the hole-type injector.

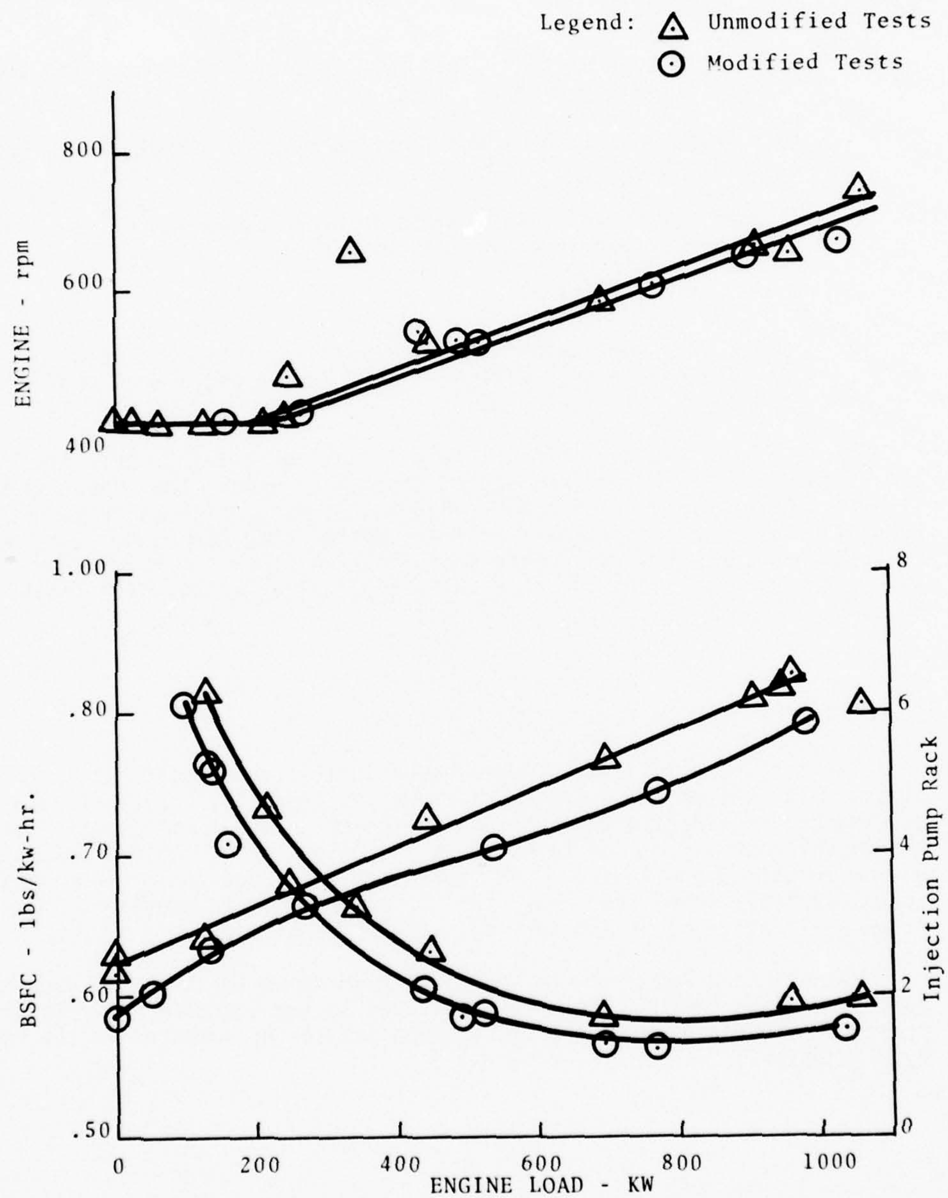

FIGURE 11. DIESEL ENGINE FUEL CONSUMPTION - USCG MACKINAW (WAGB-83)

APPENDIX A

FM REPORT ON WEAR EFFECTS WITH 3-HOLE AND PINTLE NOZZLES

COLT INDUSTRIES
FAIRBANKS MORSE INC. - BELOIT, WISCONSIN

INSPECTION REPORT

ON THE 38D8-1/8 ENGINE INVESTIGATION

FOR CANADA STEAMSHIP LINES, LTD.

1966 SEASON

Circulation:

W. Johnson, Canada Steamship Lines Ltd.
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Author: V. T. Stonehocker
Chief Project Engineer

Date: May 1, 1967

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ENGINEERING REPORT FAIRBANKS MORSE INC	SHEET 1 OF 21 PAGE NO. 1 FILE NUMBER R-5.15-4018(CSL)
REFERENCE NUMBER	DATE May 1, 1967 PREPARED BY V.T. Stonebocker
SUBJECT 1966 CYLINDER LINER WEAR REPORT CANADA STEAMSHIP LINES (CSL)	APPROVED BY

INTRODUCTION

An inspection of some of the model 38D8-1/8 Main Propulsion Diesel Engines in vessels of the Canada Steamship Lines was made at the end of the 1966 seaway season. This inspection was to study the effect of changes in components and operating conditions on cylinder, piston, and injection nozzle conditions. These changes were agreed on at the beginning of the 1966 season by representatives of CSL, FM Beloit, FM Canada, Robert Morse Corporation and Imperial Oil Company of Canada.

The findings indicate that while no improvement has been experienced in cylinder liner wear rate with standard iron liners, including the pocket, the projected wear life requirements of CSL (20,000 hours) can be obtained with chrome plated liners, standard pistons and rings. However, it is significant to note that there has not been a single engine failure due to main power components in any of the vessels with 38D8-1/8 engines. In fact, engines have been in operation for some 6000 hours with no more than a top ring replacement on the lower pistons. There has been no significant contamination of the lube oil inspite of a pocket in the liner bore now up to a maximum of .057 inches in one cylinder.

Fuel injection nozzle tips applied with modified adapters show none of the tip face errosion evident in the previous seasons.

The general condition of the engines was somewhat carbonaceous, particularly the pistons. Although there was no evidence that this effect had caused trouble or caused any of the piston rings to be stuck or gummy, it was considered unfortunate that another brand of lubricating oil had not been used to provide comparative results as had been planned. Analysis of the lube oil showed no significant contamination nor treds in wear rate. Table I shows lube oil consumption, viscosity, and iron or chrome content as determined from the lube oil sample analysis.

Fuel oil analysis showed a better control of sulfur content; this being half of the value of samples taken in 1965.

While it can not be claimed that the problem of abnormal cylinder liner wear as shown by engines in the CSL vessels has been solved, it is considered that the program, as set out at the beginning of the season, has been fully accomplished, and has provided valuable information for the continued development of the 38D8-1/8 engine, and other engines of our manufacture.

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	PREPARED BY V.T. Stonehocker	
SUBJECT 1966 CYLINDER LINER WEAR REPORT CANADA STEAMSHIP LINES	APPROVED BY	

ANALYSIS OF INSPECTION

Ships Inspected: The ships inspected at the end of the 1966 seaway season included the following:

1. M/V Manitoulin at Windsor
2. M/V Fort Chambly at Windsor
3. M/V Fort St. Louis at Hamilton
4. M/V Saguenay at Contre' Coueur
5. M/V Simcoe at Montreal
6. M/V IroQuois at Kingston

Engine Operation: It appears from the ships logs that throughout the season, loading, exhaust temperature, jacket water outlet temperature, and lube oil temperature have been within the limits specified in the program. Port plugging has been evident in some vessels as shown by the high exhaust temperatures and scavenging pressures recorded on the logs. Load sharing appears to have improved since our visit to the M/V Saguenay in May.

CYLINDER LINER WEAR RATE

A comparison of average liner wear rates has been made to show the trends under the various combinations of liners, rings, and nozzles. This data is shown in Table II and in Figure 1.

In some engines, readings were taken in liners which had been charted last year to note trends in wear rates. These showed a gauge datum discrepancy. This was corrected by splitting the average difference between readings taken in the unworn part of the liner.

Iron Liners with Ferrox Rings: On the M/V Saguenay, readings from the original liners have been compared with those from liners fitted at the beginning of the 1966 season. In the pocket, there is no reduction in wear. At .006 in. per thousand hours, it must be considered as heavy. Readings from No. 3 engine, opened for the first time this year, did not show any variation in wear pattern from that on the No. 1 and 2 engines. It is therefore concluded that the nozzle holder modifications have not been significant in eliminating the pocket.

In the Fort St. Louis, No. 2 engine, the readings taken at the end of the 1965 and 1966 seasons show an increase in wear rate in the area above and below the combustion chamber but not in the pocket. The readings from No. 4 engine appear to show less wear in all areas except the pocket.

In the Fort Chambly, the wear rate in the athwart ships combustion chamber is as high as that in the pocket on the engines with Bosch type nozzles.

Iron Liners with Chrome Rings: With this combination, there appears to be a 50 percent reduction in wear rate in all areas except the pocket where the reduction is only about 25 percent. This combination has not been considered successful because of the condition of the rings at the time of disassembly.

Chrome Liners with Ferrox Rings: Wear rates with this combination in the engines of the Fort St. Louis and Fort Chambly compare very closely, but show a somewhat higher rate in the upper end of the cylinder when compared with similar readings from engines in the M/V IroQuois having oil bath filters while the Fort Chambly and Fort St. Louis have mesh panel filters.

On engines on which filter dog houses had a considerable amount of dirt inside them, the lower cylinder wear rate was approximately 35 percent of the rate of the upper end. The chrome plated cylinders showed far less wear than the black iron liners and showed less tendency to form the pocket. Wear rates for the two seasons on the Fort St. Louis engine were not significantly different.

General Condition of Liners: Scuff marks, in some cases covered by dark brownish varnish, appeared in quite a number of both the iron and chrome liners. There was no pattern to the patches nor any reason to explain their presence. As the rings did not have any scuff marks, or evidence of blow-by, it was not considered that the scuff marks on the liners had produced any adverse affect on the cylinder efficiency.

PISTONS AND PISTON RINGS

A comparison of the condition of the pistons, piston rings and cylinder liner surfaces is given in Table III.

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Pistons and rings were generally in good condition. Crowns were clean but had a pattern of red ash down stream of the injection slot on the edge of the crown. No significance has been attached to this, although analysis of the ash indicated that it was essentially a sodium salt. Number 1, 2, and 3 piston ring grooves showed a considerable build up of hard carbon in the back of the rings. The No. 4 groove was generally clean. There was no evidence to show that this carbon had interfered with the freedom of the rings and their seating. The piston skirts had large areas of a hard lacquered carbon with only a small area of relief on the thrust side. The more lightly coated pistons showed port marks indicating that this lacquer could be caused by blowdown of adjacent cylinders.

Piston ring groove wear was fairly generally evident, but in no case did it indicate that it had been the cause of bad seating, blow-by or ring failure. Piston ring seat witness was quite varied, in many cases showing an inner and outer annular mark. This may be due to deflection of the piston groove ledge and the normal way in which this seat wears. It was particularly noticable where the ring had been replaced without piston groove reconditioning. It was noted that the ring seat witness on some rings was at the inside corner, indicating that the tool used to regroove the piston had too much radius at the tip. This condition resulted in the wearing of a heavy taper at the top corner of the ring (.006 inches deep at an angle of 4-1/2 degrees) indicating that the ring had been twisting about this narrow seat.

Several top rings were broken on both upper and lower pistons. However, none of these were in the same liner. In most cases the break was at least one third the way around from the gap and had occured early in its life. This has been attributed to over-stressing at assembly or a material defect. The vendors have corroborated this view point on an inspection of some of the rings. In one case, the broken ring had gouged out two of the airport bridges on the Fort St. Louis No. 2 engine in cylinder No. 3.

The chromium plated piston rings performed poorly. Most of the chrome had been worn off, and rings were collapsed to some extent, and showed partial blow-by marks. Their manufacturer considered these rings had a rather short life. Their effect on the cylinder wear rate was to reduce it slightly but not significantly in the pocket. None of these conditions were evident in the Ferrox (black) rings and it has been concluded that the high temperatures which would induce ring collapsing may have been caused by poor ring seating, partial blow-by and by possibly scuffing. As the chrome ring does not provide any real improvement under these operating conditions, it is felt that it should not be used in the future.

Fuel Oil & Lube Oil Analysis

The main difficulty experienced in carrying out the program set out at the start of the 1966 season was that of getting the necessary data forwarded to FM Beloit. This was particularly true with respect to the lube oil and fuel oil analysis and the ships logs and operating information. Fuel oil sample data was very sparce. The predominance of sample analysis received by FM Beloit were from the M/V Fort William, which was not inspected at the end of the 1966 season. The remaining samples were primarily from the M/V Saguenay. There was one sample analysis from each of the Fort St. Louis, Manitoulin, and Fort Chambly.

Figure 2 shows typical fuel distillation curves from the 1966 season compared to the "normal" diesel fuel destillation curve. It is interesting to note that the fuels used on the Fort William, procured, from B/A, were very near the "normal" distillation curve. Imperial Oil samples 14 and 16, used on the Saguenay, are typical of fuels containing catalytically and/or thermally cracked fuel stocks. Most of the rest of the samples of Imperial fuel oils indicate a predominence of heavy ends typical of the "economy" fuels.

One sample from the Saguenay showed .76 percent Sulfur content. Other samples rnged between .25 and .40 percent Suflur. The fuel oil was not specifically analyzed for sodium and vanadium content. Future sample should be so analyzed.

With the small number of fuel oil samples from the other ships, no real conclusions can be drawn with regard to the affect of the fuel oils. It is felt that the fuel oil quality can be questioned, and one oil company has made the statement that if the fuesl available in Canada continue to get worse, they are not certain they can provide oils properly compounded to cope with the fuel.

In comparing 1966 and 1965 lube oil analysis, it was anticipated, in the mid 1966 discussions, that at the time of inspection, we would see up to 50% reduction in wear rates. This has not been true and it is pointed out that the spectrographic analysis of wear metals in the lube oil samples is not a reliable method of monitoring wear in the engine.

Again, it is considered unfortunate that another brand or type of lube oil had not been tried in one of the ships to provide a comparison, as had been planned in the program outlined at the beginning of the season. The following laboratory analyses are an attempt to provide some comparative information.

LUBE OIL COMPARATIVE TESTS

One gallon samples of Imperial Oil 2054 and our Test Oil were sent to a Laboratory in Chicago for comparative analysis. The test results are tabulated below. Sample "A" is the Imperial 2054 Oil being used by CSL. Sample"B" is a comparable oil of another manufacture and is the normal test oil used in our laboratory engines and on our production test floor.

TABLE IV

Results Of Lube Oil Analysis

Primary Properties	A	B
Viscosity - @ 100°F S.U.S.	718	592
- @ 130°F S.U.S.	296	241
- @ 210°F S.U.S.	69	61.2
Viscosity Indes	76.5	61.9
Total Base No. mg KOH/g - New	5.2	3.48
Total Acid No. mg KOH/g	.03	0.47
PH Value	10.4	10.2
Spectrographic Analysis		
Base	Organic	Organic
Major	Calcium	Calcium
Minor	Copper; Iron	Copper; Iron
Traces	Silver; Titanium; Silcon; Lead; Tin; Magnesium	Same as A
Wear Test - on Shell 4 Ball Wear Tester (New Oil)		
(14 kg load, 1800 RPM, 2 hrs., 180°C.) Average wear spot diameter - mm	.308	.308
Corrosion - Oxidation Tests		
S.O.D. Lead Corrosion Test mg/sq. in. - loss	.69	.32

Corrosion - Oxidation Stability Tests	A	B
48 hours @ 347°F.		
Tests on New Oil:		
Viscosity - 100°F. SUS	718	592
Acid No. mg KOH/g	0.03	0.47
Tests on Oxidized Oil:		
Viscosity - 100°F SUS	988	774
Acid No. mg KOH/g	4.03	2.67
Evaporation loss - %	0.47	0.84
Increase in Viscosity - %	37.7	30.7
Increase in Acid No.	4.0	2.20

Appearance after oxidation in both cases was dark brown, with no precipitate.

Loss of Weight of Metals - mg/sq. - cm.	A	B
Magnesium	0.00	0.01
Aluminum	0.00	0.00
Copper	0.81 *1	0.15 *2
Cadmium	0.04 *3	1.16
Steel	0.00 *4	0.00

*1 - Bright Etching
*2 - Dark Tarnish - 3B; etched
*3 - Brown Stain
*4 - Gold Stain

Vapor Pressure Test - (Isoteniscope Method)

See the curves of Figure 3
Region of instability - 383-463°F 400-500°F

"The knee in the curves suggest that there is an unstable component present which after reaching its decomposition temperature is degraded rapidly leaving the bulk of the sample relatively unchanged. After loss of this component the remainder of the sample is stable and does not exhibit further evidence of thermal decomposition until 600°F. This effect is much more pronounced in 'A' than in 'B'."

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PREPARED BY V.T. Stonehocker

SUBJECT 1966 CYLINDER LINER WEAR REPORT CANADA STEAMSHIP LINES

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Oil Detergency Test

Again quoting from the laboratory reports, "The detergency characteristics of Sample A were not as great as those of Sample B. If the characteristics for Sample B were expressed as excellent, then those of Sample A would be expressed as Fair to Good." The results of these tests are tabulated below:

Detergency Tests (500°F)

Sample	A	B
Insoluble in Naphtha (mg)	77.3	8.5
Insoluble in Naphtha but soluble in Chloroform (mg)	9.3	3.9
Insoluble in Naphtha and Chloroform but removable by wiping (mg)	1.8	.5

Infrared Absorbtion Test:

The infrared absorbtion tests on the new oils showed the oil to be quite similar. However, the tests on oxidized oil samples (48 hrs. @ 347°) show the sample "A" to have a much greater tendency to oxidize. The following data is quoted directly from the Chemical laboratory report: "The infrared spectra of both oxidized oils were similar in their general characteristics. Each exhibited a band at 1700 cm^{-1} which did not appear in the spectra of the new samples. A band at this location is due to carbonyl and might represent the presence of ester, ketone, or carboxylic acid groups which are produced as a result of oxidation. The intensity of the carbonyl band is much greater for Sample A than for Sample B, indicating more extensive oxidation in the case of Sample A."

Comments on Analysis:

In most values, these oils seem quite comparable. However, the 2054 appears to have a greater tendency to instability, oxidation and corrosion. While the oil company has stated that with the organic additives used in compounding this oil the normal parameters of TAN, TBN, Pentane and Bensene insolubles, can not be relied upon, it is our feeling that the above data does indicate and inadequacy in this oil. We believe that the oil is not capable of proper lubrication at temperatures, in the environment that does exist in the ring belt area and compression ring travel in this engine.

The oil company has suggested the use of a heavy weight of oil (SAE 40) as a means of reducing upper cylinder wear. The sample submitted was supposedly SAE 30 and was compared to our SAE 30 weight test oil. In reality, the 2054 oil is near a SAE 38 if oils were so graded. In as much as some problems with oil distribution could be anticipated with even heavier weights, without concurrently raising lube oil system temperatures, this approach is not recommended, as an adequate solution.

CONCLUSIONS

1. Our investigation indicates that a cylinder liner life of twenty thousand hours between major engine overhauls can be obtained, on present fuel and lube oils, by using Chrome plated cylinder liners with "standard" piston compression rings and conformable oil control ring in the middle oil ring groove.

2. We believe that an even longer cylinder life is obtainable on better grades of fuel oil and/or by changing to higher additive level lube oils.

3. Better air filtration on those engines with the screen panel type air filters would enhance, particularly, the air end cylinder wear.

4. Comparison of piston ring groove wear showed a trend to indicate that reducing liner wear rates also reduces the ring groove wear rate.

5. The Imperial 2054 lube oil shows a tendency to break down at temperatures that do exist in the ring band and upper ring travel areas in this engine design.'

6. It will be noticed that the Imperial Lube oil has a much greater tendency to corrosion of copper. This was evident in a piston assembly inspected on the Ft. St. Louis in that the piston pin has a discoloration indicating a metalic transfer of material had occured between the pin and the piston insert bushing - which is bronze. This tendency has been evident in at least one other Canadian Ship using an Imperial lube oil. This was not evident on the oil previously used.

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7. Some of the fuel oil analysis indicated the possible use of cracked fuel stocks.

8. Technical data indicates that a comparison of the wear rates between a bad liner material and a good liner material might vary up to a maximum of 4 to 1, in wear rate. The fact that wear rates in the CSL engines of 10 to 12 times that expected of good material points to there being factors other than material contributing to the wear rates experienced in these engines. It is the contention of this report, based on past experience, with great similarity to the CSL engine problem that the fuel oil and lube oil are not compatible. One or the other of these needs to be changed.

9. It is again suggested, that for comparative purposes, a lube oil of another type and manufacture be tried in one of the CSL Vessels.

10. Nozzle tip errosion, as experienced in past years, can be overcome by adopting the type B modification nozzle holder.

11. The Bosch type injection nozzle is superior to the FM nozzle from at least two standpoints:

    a. Crankcase dilution
    b. General engine wear pattern

12. Engine operation is safe up to and beyond the cylinder wear dimensions found in the CSL engines (.057" pockets and .030" athward ships) without adversely affecting the operation of the engine, or the lube oil life and without compression ring breakage.

13. Better surveillance of the engines by the operating crews this year has resulted in many less calls for assistance in engine, governor and associated problems.

14. If the customer continues to use the "economy" grades of fuel, he must concurrently expect and be willing to pay the increased cost of maintenance of his engines.

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RECOMMENDATIONS

The following are the recommendations of this report and are intended to insure the best possible engine life and operation for CSL.

1. The chrome plated cylinder liners, as plated by Union Screen Plating Co., Ltd, Lennoxville, should be adopted as the standard for these engines.

2. Air filtration on all engines should not be less than the felt panel type filters.

3. Engine operating perameters as follows should be adopted:

   a. Engine J.W. Temperature - out 170-180°F
   b. Engine L.O. Temperature - out 190°F maximum
   c. Fuel oil analysis should fit F.M. specifications
   d. Lube Oil to be to the FM specified oils as a minimum and if Fuel oil sulfur contents are allowed to exceed .5% (as specified) a series III additive level must be adopted, and if heavy oils are used, even with low sulfur, higher additive levels are recommended.

4. If fuel oils not meeting our specifications are to continue to be used, it is recommended that a fuel oil additive be tried. Our specific recommendation is to investigate the use of Perolin Fuel Oil Treatment No. 687-SD (Perolin Company, Inc., Empire State Bldg., New York, New York) in dosage of 1 part of treatment to 3000 gallons of fuel oil. At this dosage, estimated cost would be $.003 per gal. (US).

5. In regrooving piston rings for over width compression rings, the groove seat should be very carefully machined and inspected before putting the new rings in. Radius at the inside of the grooves must not be too large.

6. It is recommended that the ship crews continue to keep daily logs on the engines, logging all important temperatures and pressures in order to detect engine problems before such problems grow out of proportion.

TABLE No. I

ENGINE OIL DATA RELATIVE TO OPERATING TIME

. LEGEND TO FIGURE I.

Liner • N.D. = No Data; N.C. = not replaced but charter
Liner type- C.I. = Cast Iron, C.P. = Chrome Plated
Ring type-- S = Standard, C = Conformable oil rings, O = Overwidth

SHIP	ENG HRS	HRS LAST SAMPLE	TOTAL OIL USED I.GALS	OIL LAST SAMPLE I.GALS	U.S. BHP-HR / GAL	VISCOSITY @ 210°F SUS	LINER 1965	LINER TYPE	RING TYPE	SAMPLE DATE 1966	IRON CHR-OME PPM
M/V	2585	2585	691	691	4145	62.2	N.C.	C.I.	S	4/30	189
FORT CHAMBLY	3129	544	866	175	3450	61.5	"	"	"	5/31	109
ENG. NO. 1	3339	210	894	28	11000	--	"	"	"	6/13	--
8 CYL.	New Oil										
	3692	353	20	20	19400	64.2	"	"	"	6/30	84
	4327	635	90	70	10000	62.8	"	"	"	7/31	96
	6033	1706	315	225	8420	60.2	"	"	"	11/1	83
	6477	444	385	70	7050	60.6	"	"	"	11/29	80
			SEASON AVG.		7350						
M/V	278	278	110	110	2800	64.8	NEW	C.P.	C	4/30	43
FORT CHAMBLY	697	419	270	160	2800	64.4	"	"	"	5/31	26
ENG. NO. 2	1222	525	355	85	6825	65.1	"	"	"	6/30	18
8 CYL.	1849	627	445	90	7700	64.4	"	"	"	7/31	14
	3501	1652	770	325	5650	62.8	"	"	"	11/1	*42
	3985	484	895	125	4300	62.7	"	"	"	11/29	37
					5250						
M/V	2142	2142	1142	1142	2600	63.3	N.D.	C.I.	S	4/30	46
FORT CHAMBLY	2420	278	1217	75	5160	--	"	"	"	5/31	--
ENG. NO. 3	2664	244	1302	85	4000	63.8	"	"	"	6/30	59
10 CYL.	2923	259	1437	135	2670	--	"	"	"	7/31	--
	4063	1140	1752	315	5030	63.2	"	"	"	11/1	64
	4205	142	1837	85	2325	--	"	"	"	11/29	--
					4130						
M/V	1980	186	50	50	5190	64.4	N.D.	C.I.	S	4/30	65
FORT CHAMBLY	2320	440	135	85	7210	--	"	"	"	5/31	--
ENG. NO. 4	2520	220	210	75	4090	63.2	"	"	"	6/30	80
10 CYL.	2816	276	285	75	5120	--	"	"	"	7/31	--
	3595	779	605	320	3380	62.0	"	"	"	11/1	64
	3743	148	700	95	2170	--	"	"	"	11/29	--
					3770						

* Water Leak

TABLE I

Sheet 1 of 3

TABLE No. I

ENGINE OIL DATA RELATIVE TO OPERATING TIME

SHIP	ENG HRS	HRS LAST SAMPLE	TOTAL OIL USED I.GALS	OIL LAST SAMPLE I.GALS	U.S. GHP-HR / GAL	VISCOSITY @ 210°F SUS	LINER 1965	LINER TYPE	RING TYPE	SAMPLE DATE 1966	IRON CHR-OME PPM
M/V	3176	3176	2173	2173	1620	67.5	N.C.	C.P.	C.O.	5/1	17
FORT ST.LOUIS	3610	434	2338	165	2910	70.3	"	"	"	6/2	19
ENG NO. 1	4033	423	2466	128	3650	73.3	"	"	"	7/1	17
8 CYL.	CENTRIFUGE	WATER	IN OIL	7%	--	136.4	"	"	"	8/25	--
	4861	828	2696	230	3980	69.6	"	"	"	9/1	16
	5611	750	2861	165	5040	70.6	"	"	"	11/2	*23
	6130	519	3026	165	3500	71.5	"	"	"	12/15	*18
			SEASON	AVG..	3860						
M/V	3014	3014	1572	1572	2120	68.9	N.D.	C.I.	S	5/1	92
FORT ST.LOUIS	3383	369	1727	155	2630	--	"	"	"	6/2	--
ENG. NO. 2	3749	366	1845	118	3425	69.6	"	"	"	7/1	91
8 CYL.	CENTRIFUGE	WATER	IN OIL	.2%	--	78.2	"	"	"	8/25	--
	4404	655	2183	338	2150	68.5	"	"	"	9/1	88
	5035	631	2413	330	2125	70.3	"	"	"	11/2	64
	5467	432	2618	205	2345	71.0	"	"	"	12/15	85
					2660						
M/V	347	247	150	150	2300	68.5	NEW	C.I.	S.O.	5/1	80
FORT ST.LOUIS	564	317	335	185	2380	--	"	"	"	6/2	--
ENG. NO. 3	884	320	508	173	2570	69.7	"	"	"	7/1	65
10 CYL	1459	575	863	355	2250	70.4	"	"	"	8/25	73
	1998	539	1228	365	3050	69.0	"	"	"	9/1	57
	2469	471	1388	160	4100	70.1	"	"	"	11/2	75
					2460					12/15	
M/V	194	194	190	190	1420	68.8	NEW	C.I.	S.O.	5/1	87
FORT ST.LOUIS	467	273	340	150	2530	--	"	"	"	6/2	--
ENG. NO. 4	654	187	513	173	1500	69.7	"	"	"	7/1	81
10 CYL.	1287	633	764	251	3500	70.1	"	"	"	8/25	78
	1771	484	1024	260	2590	70.0	"	"	"	9/1	72
	2115	344	1145	121	3950	70.1	"	"	"	11/2	83
					2800					12/15	

* Water Leak

TABLE I

Sheet 2 of 3

BF3010A
For Use of Form see
Stds. No. BF3010A)

ENGINEERING REPORT FAIRBANKS MORSE INC.	SHEET [illegible] OF	PAGE NO. [illegible]
	FILE NUMBER	
REFERENCE NUMBER	DATE [illegible]	
	PREPARED BY V. T. Stonehoc[illegible]	
SUBJECT: 1966 CYLINDER [illegible] REPORT CANADA [illegible]	APPROVED BY	

DEVELOPMENT PROGRAM

As a part of our long-range development program, several projects are of interest in connection with the CSL program. These are enumerated and discussed here below.

Piston Rings: The barrel faced, taper land piston ring has been developed in conjunction with our ring vendors. The new design has been tested in our laboratory test engines as well as in a number of field applications. Both ring wear and liner wear results with this new ring configuration are very encouraging. This ring was put into production during August of 1966 and will be available for engine rebuilds.

This new ring design was tested for some time in engines on Ohio Barge Lines "push boats" and, while we have not had an opportunity to chart the cylinder bores, visual inspections of the rings and liners indicate that the rings and liners are in excellent condition. This ring is also on test in our 6 cylinder turbocharged test engine, on chrome plated cylinders, and initial results are excellent. Both of these tests, OBL and the lab engine, show a phenominal reduction in lube oil consumption requirements along with this improvement in wear in the cylinder system.

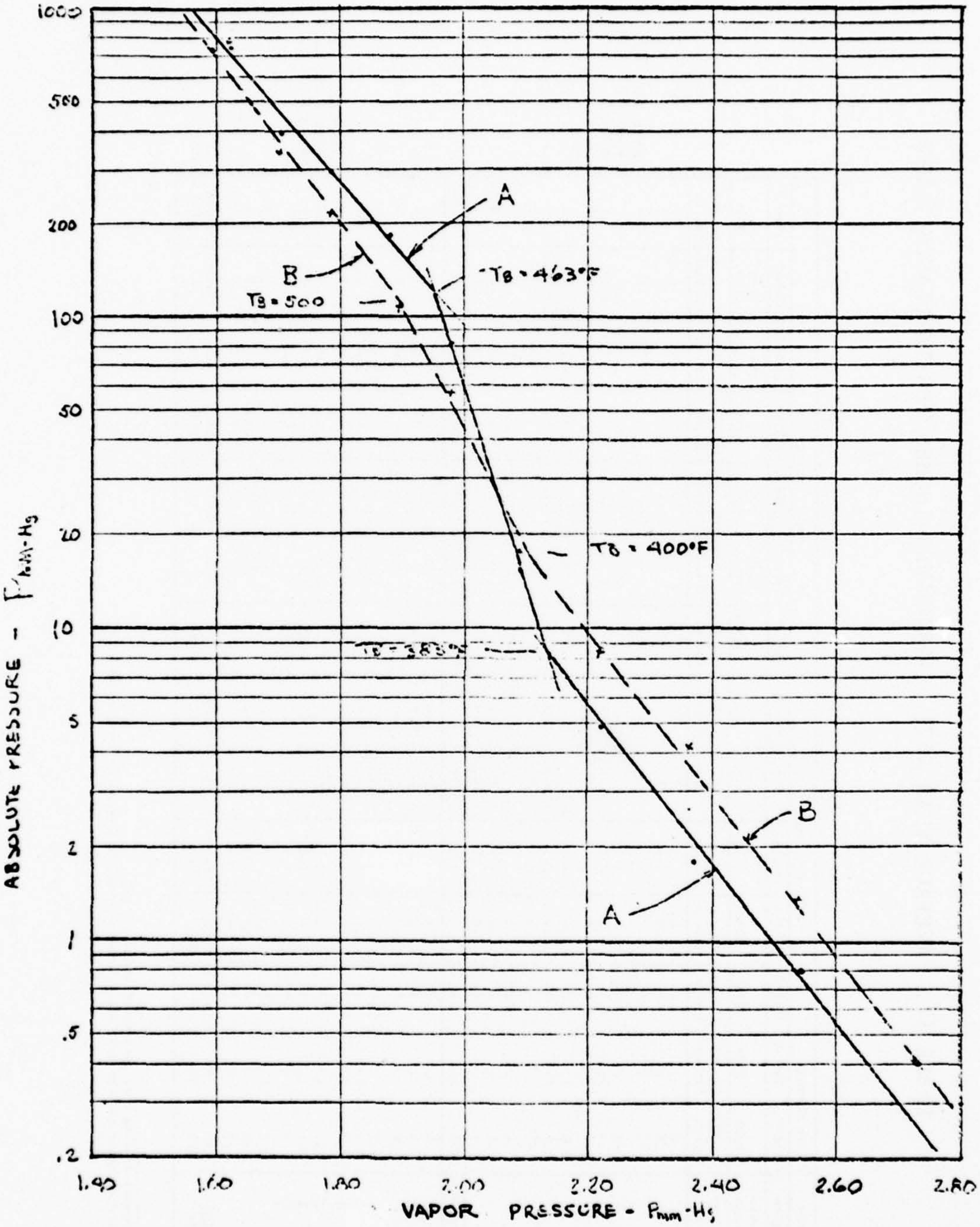
Cylinder Liners: The investigation of new liner materials, specifically a Titanium-Vanadium alloying, is continuing. The metalurgy is presently being evaluated inthe 38A20 test program. Foundry problems in connection with the 8-1/8 cylinder liner of this allow have not yet been resolved.

Investigation into better production and quality control methods on our present liner material is also continuing. New or better equipment to monitor hardness, microstructure and surface finish are being obtained or investigated. Other methods of finishing the liner bore surface are under study.

A change was made to relieve the fits at the ends of the liner jacket, to reduce the residual stress level in the area around the intake and exhaust prots, thereby reducing the port distortion due to temperature changes in engine operation.

Pistons: A new piston design is under test in the laboratory engine. Many more hours of testing are required to fully evaluate this new design in every possible situation. The new design does appear to influence piston ring and cylinder life in a positive direction.

The basic piston design incorporated less "bull ring" taper, omission of the cam ground clearance on the "bull ring", three compression rings (rather than 4) and modified piston skirt tapers. A piston assembly design incorporating the above design with a rotating piston and a simplified wrist bearing is also being investigated. It has also been suggested that in the design of a new piston, the first ringland (ring groove ledge) be increased in width (depth) to both strengthen it and to allow for the weakening that occurs from regrooving for over-width compression rings.



VAPOR PRESSURE CHART
ISOTENISCOPE METHOD

FIGURE 3.

TABLE II. AVERAGE WEAR RATE - THOUSANDS INCHES PER THOUSANDS HOURS

Ship	Fort Chambly		Fort St. Louis					Saguenay							
Engine	1966-1	1966-2	1965-1	1966-1	1965-2	1966-2	1966-4	1965-1	1966-1	1966-1	1965-2	1966-2	1966-2	1966-3
Liner Hours	3325	2773	2826	3304	2723	2744	2115	4198	odd 2660	even 2660	4630	odd 2810	even 2810	5964
Liner Top Ring	C. IRON Ferrox	Chrome Ferrox	Chrome Ferrox	Chrome Ferrox	C. Iron Ferrox	C. Iron Ferrox	C. Iron Ferrox	C. Iron Ferrox	C. Iron Ferrox	C. Iron Chrome	C. Iron Ferrox	C. Iron Ferrox	C. Iron Chrome	C. Iron Ferrox
Fore and Aft														
A1	1.0	.2	.1	.2	.7	.2	.5	.6	.5	.5	.3	.5	.5	.3
B1	.7	.1	.1	.0	.4	.0	.5	.3	.2	.4	.1	.3	.3	.1
C1	.7	.9	.8	.7	.3	.0	.7	.4	.2	.4	.2	.4	.3	.2
D1	.6	.4	.4	.2	.4	.3	.5	.4	.2	.4	.3	.4	.4	.2
E1	1.4	1.1	1.1	1.1	.8	2.0	.7	1.2	1.3	1.6	.7	1.9	1.9	.7
F1	1.7	1.6	1.6	.9	1.6	2.8	.9	1.6	1.7	2.0	1.2	2.4	2.6	.9
G1	4.0	1.5	1.0	1.4	3.6	2.5	2.4	5.2	4.0	2.5	6.3	4.1	2.2	3.8
H1	3.0	1.1	.8	1.2	2.9	2.5	1.9	4.7	3.1	2.1	5.3	3.4	1.5	3.4
I1	.5	.0	.2	.1	.4	.0	.2	.3	.0	.2	[illegible]	.2	.2	.2
J1	.4	.8	.6	.0	.3	.0	.3	.3	.0	.2	.2	.2	.3	.1
K1	.4	.1	.2	.0	.4	.0	.3	.3	.0	.2	.1	.3	.0	.0
L1	.5	.1	.1	.0	.5	.0	.4	.5	.1	.3	.3	.4	.2	.2
G-Pocket	Nil	Nil	1.4	1.4	4.1*	3.3*	5.7	5.8*	7.3	5.7	6.8*	6.5	5.3	5.5**
Athwart Ships														
A2	.0	.4	.3	.2	.0	.0	.4	.1	.0	.0	.1	.2	.2	.0
B2	.5	.3	.4	.0	.6	.0	.8	.5	.3	.5	.3	.6	.5	.3
C2	1.0	.8	.8	.2	1.0	.0	1.2	.8	.8	.9	.7	1.0	.9	.7
D2	1.9	.5	.8	.1	1.3	.2	1.3	1.1	1.0	1.3	1.0	1.4	1.4	1.1
E2	2.4	2.0	1.2	1.1	1.2	1.9	1.6	1.4	2.2	2.1	1.0	2.6	1.7	1.3
F2	2.8	2.3	1.9	.7	1.9	1.7	1.9	1.7	2.6	2.6	1.7	[illegible]	2.1	1.5
G2	6.3	1.7	1.0	.6	2.7	2.2	2.2	2.5	2.5	1.0	3.4	3.7	1.8	2.4
H2	5.7	1.3	.7	.6	1.8	2.4	1.7	2.1	2.0	1.1	3.0	2.9	1.4	2.0
I2	3.1	.5	.6	.3	1.9	.7	2.9	1.8	2.4	2.3	1.7	2.3	2.5	1.5
J2	1.2	1.2	.8	.5	.7	.0	1.0	.7	.5	.8	.4	.7	.8	.5
K2	.5	.0	.0	.0	.2	.0	.2	.2	.0	.0	.0	.2	.1	.0
L2	.3	.0	.0	.0	.0	.0	.1	.0	.0	.0	.0	.2	.1	.0
Nozzle Type	FM STD	FM STD	Bosch STD	Bosch STD	Bosch STD	Bosch A	Bosch B	Bosch STD	Bosch B	Bosch B	Bosch STD	Bosch A	Bosch A	Bosch STD

	G_1	F_1
BOSCH STD	4.72	1.33
BOSCH A	3.30	2.6
BOSCH B	3.20	1.3

	G_2	F_2
BOSCH STD	2.75	1.65
BOSCH A 15°	2.95	2.45
BOSCH B 10°	2.35	2.25

*Several Reading Over Bore Gauge Range.
**Several Readings Over Bore Gauge Range - Gauge Readjusted to find Maximum.

SHIP	ENG#	TOP PISTON RING Type	Wear	Land Seat	Face Seat	Side Clearance	No. Broken	PISTON Crown	Bull Ring	Skirt	Groove Wear	Piston Pin	[illegible] CONDITION Bore	Ports	Nozzle Adapter Type	Condition
MANITOULIN	1	Ferrox	Normal	Good	Good	.010-.012	0	Dry Carbon	Hard Carbon	Soft Carbon	Normal	--	-	Dirty	B	O.K.
	2	Ferrox	Normal	Good	Good	.010-.012	0	"	"	"	"	--	--	Dirty	B	O.K.
	3	Ferrox	Normal	Good	Good	.010-.012	0	"	"	"	"	-	--	Dirty	B	O.K.
	4	Ferrox	Normal	Good	Good	.010-.012	0	"	"	"	"	--	--	Dirty	B	O.K.
FORT ST LOUIS	1	Ferrox	Normal	Good	Good	.009-.012	0	Clean	"	Clean-Rel.	"	-	[illegible] Varn.	--	STD	Erosion
	2	Ferrox	Normal	Good	Good	.009-.012	1	"	"	"	"			--	A	O.K.
	3	Ferrox	--	--	--	---	-	---	--	---	--		----	--	B	--
	4	Ferrox	Normal	Poor 10%	Good	.009-.010	0	Clean	"	"	Inner Edge	--	Lt. Varn.	--	B	O.K.
FORT CHAMBLY	1	Ferrox	Normal	Poor	Good	.010-.013	2	Carbon Haze	Heavy Carbon	Carbon & Varn.	Inner Edge	Slight Wear	Heavy Varnish	Normal Dirt	F.M.	O.K.
	2	Ferrox	Normal	Good	Good	.009-.011	0	Carbon Haze	Heavy Carbon	Carbon & Varn	Normal	Slight Wear	Light Varnish	Normal Dirt	F.M.	O.K.
	3	Ferrox	--	--	--	---	-	---	--	---	--	--	----	--	F.M.	--
	4	Ferrox	--	--	--	---	-	---	--	---	--	--	----	--	F.M.	--
SAGUENAY	1	Even-Chr. Odd-Ferrox	Heavy Normal	Good Good	Poor Good	.015 .014-.015	0 3	Carbon Haze	Clean	Rel. Clean	Normal	--	Patches Heavy Varn.	Normal	B	O.K.
	2	Even-Chr. Odd-Ferrox	Heavy Normal	Good Good	Poor Good	.015-.016 .017	0 1	Carbon Haze	Clean	Rel. Clean	Normal	--	" "	Normal	A	O.K.
	3	Ferrox	Normal	Good	Good	.015-.016	0	Carbon Haze	Clean	"	"	--	Heavy Varnish	Normal	STD	Erossion
	4	Ferrox	--	--	--	---	-	---	--	---	--	--	----	--	STD	"
SIMCOE	1	Ferrox	Normal	Good	Good	---	-	Clean	Clean	Clean	--	--	----	Clean	B	--

PISTON AND PISTON RING COMPARATIVE DATA

TABLE III

TABLE III

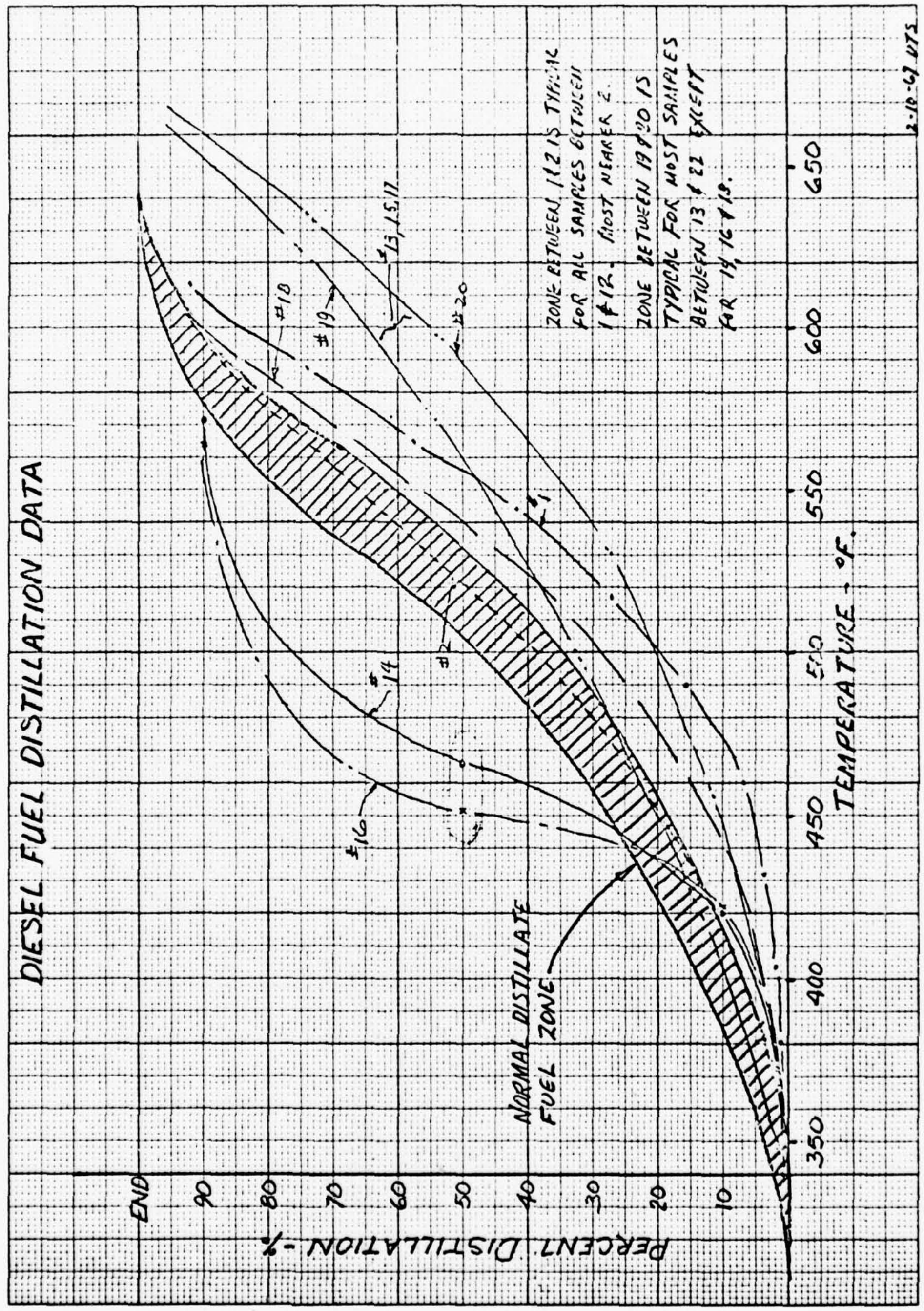
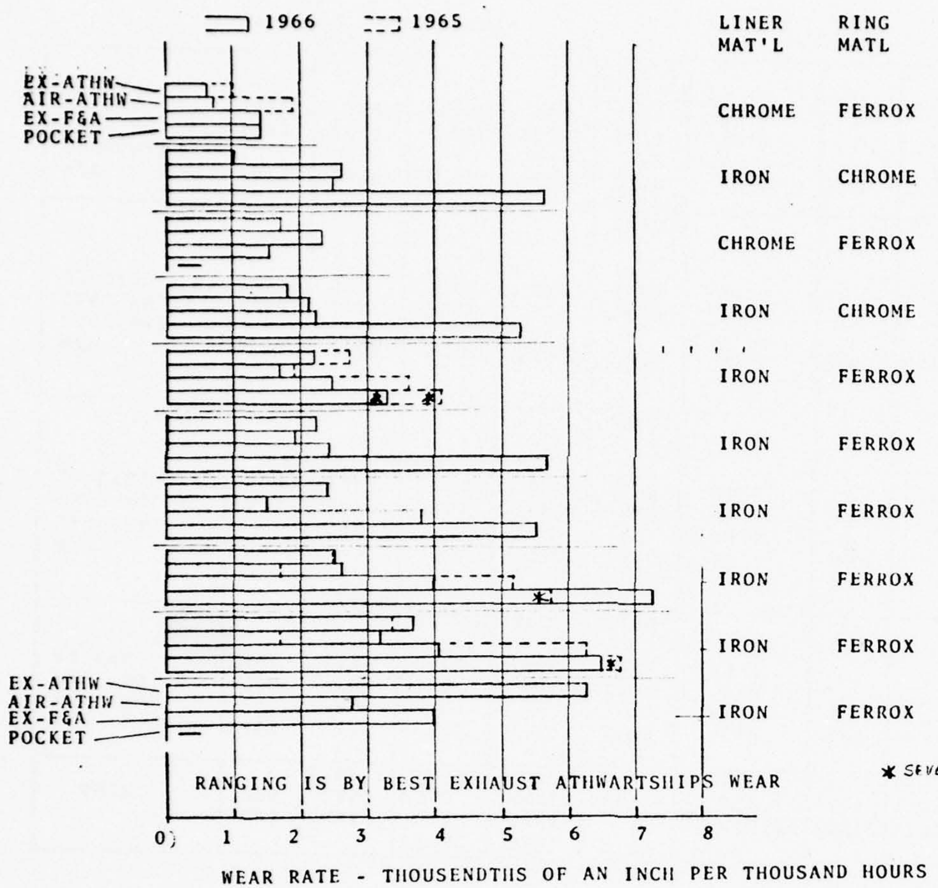


FIGURE 2.

FIGURE 2.



LINER MAT'L	RING MATL	NOZZLE TYPE	SHIP	ENGINE
CHROME	FERROX	BOSCH STD	FT.ST.LOUIS	1
IRON	CHROME	BOSCH "B"	SAGUENAY	1-EVEN
CHROME	FERROX	FM STD	FT.CHAMBLY	2
IRON	CHROME	BOSCH "A"	SAGUENAY	2-EVEN
IRON	FERROX	BOSCH "A"	FT.ST.LOUIS	2
IRON	FERROX	BOSCH "B"	FT.ST.LOUIS	4
IRON	FERROX	BOSCH STD	SAGUENAY	3
IRON	FERROX	BOSCH "B"	SAGUENAY	1-ODD
IRON	FERROX	BOSCH "A"	SAGUENAY	2-ODD
IRON	FERROX	FM STD	FT.CHAMBLY	1

* SEVERAL RDGS. OVER BORE GAUGE RANGE

FIGURE 1

FIGURE 1

TABLE No. I

ENGINE OIL DATA RELATIVE TO OPERATING TIME

SHIP	ENG HRS	HRS LAST SAMPLE	TOTAL OIL USED I.GALS	OIL LAST SAMPLE I.GALS	U.S. BHP-HR/GAL	VISCOSITY @ 210°F SUS	LINER 1965	LINER TYPE	RING TYPE	SAMPLE DATE 1966	IRON CHROME PPM
M/V	608	608	725	725	1400	68.9	NEW	C.I.	S.C.	6/1	56
SAGUENAY	--	--	--	--	--	67.2	"	"	"	7/1	--
ENG. NO. 1	1366	758	1370	645	1960	69.2	"	"	"	8/1	73
12 CYL.	2495	1129	2000	630	2990	68.9	"	"	"	12/3	109
			SEASON AVG.		2460						
M/V	702	702	710	710	1650	69.2	NEW	C.I.	S.C.	6/1	54
SAGUENAY	--	--	--	--	--	73.0	"	"	"	7/1	--
ENG. NO. 2	1579	877	1515	805	1810	70.1	"	"	"	8/1	80
12 CYL.	2662	1083	2340	825	2200	69.5	"	"	"	12/3	121
					2000						
M/V	3286	3286	3170	3170	1720	69.6	N.D.	C.I.	S	6/1	70
SAGUENAY	--	--	--	--	--	73.4	"	"	"	7/1	--
ENG. NO. 3	3969?	683	3795	625	1820	70.9	"	"	"	8/1	73
12 CYL.	4882?	913	4710	915	1660	69.8	"	"	"	12/3	96
					1620?						
M/V	2876	2876	2712	2712	1760	69.5	N.D.	C.I.	S	6/1	84
SAGUENAY	--	--	--	--	--	87.1	"	"	"	7/1	--
ENG. NO. 4	3928	1052	4050	1338	1310	70.4	"	"	"	8/1	93
12 CYL.	4714	786	4640	590	2220	70.5	"	"	"	12/3	132
					1590						

? Hours Questionable

TABLE I

Sheet 3 of 3

APPENDIX B

DESCRIPTION OF THE EXHAUST GAS ANALYSIS SYSTEM AND INSTRUMENTATION FOR THC, CO, NO/NOx, O_2 AND CO_2.

The exhaust emissions analysis system was located in the Mackinaw log office. This room is located adjacent to the engine stack area at main deck level. The instrumentation was placed on and under a table in the log office.

A twenty foot 3/8 inch diameter stainless steel sample line heated to 300°F connected the exhaust sample probe to the heated filter and heated stainless steel bellows pump. A second twenty feet of similar heated line conducted the exhaust sample to the emissions analysis system. The filter, pump and first section of sample line were located in the exhaust stack area. The second sample line passed out of the exhaust stack area through a small bulkhead door through a corridor and then into the log office.

B.1 EXHAUST ANALYSIS SYSTEM

The analytical system was configured in three parallel "legs" as shown in Figure 1. As the sample entered the analytical system, it was filtered through a heated (300°F) 7 cm clamshell filter and distributed to the three legs of the system.

The first leg was maintained at 300°F up to the total hydrocarbon analyzer, to prevent high molecular weight hydrocarbons from condensing. The sample was then allowed to cool to ambient temperature (excess water was removed through a combination of traps) and continuously supplied to the gas chromatograph for methane analyses.

The second leg of the system passed the sample through an ice bath-refrigeration coil to remove the water of combustion and then supplied the gas sample to the CO, the CO_2 and the oxygen analyzers.

The third sample leg contained the oxides of nitrogen analyzer. The hot sample was first passed through the NO_2 converter (when in the NOx mode) to convert all the NO_2 to NO. Then the sample was dried using another ice bath-refrigeration coil and transported to the NO analyzer.

Each analyzer was connected to a strip chart recorder in order to provide a permanent record of all the emission data collected.

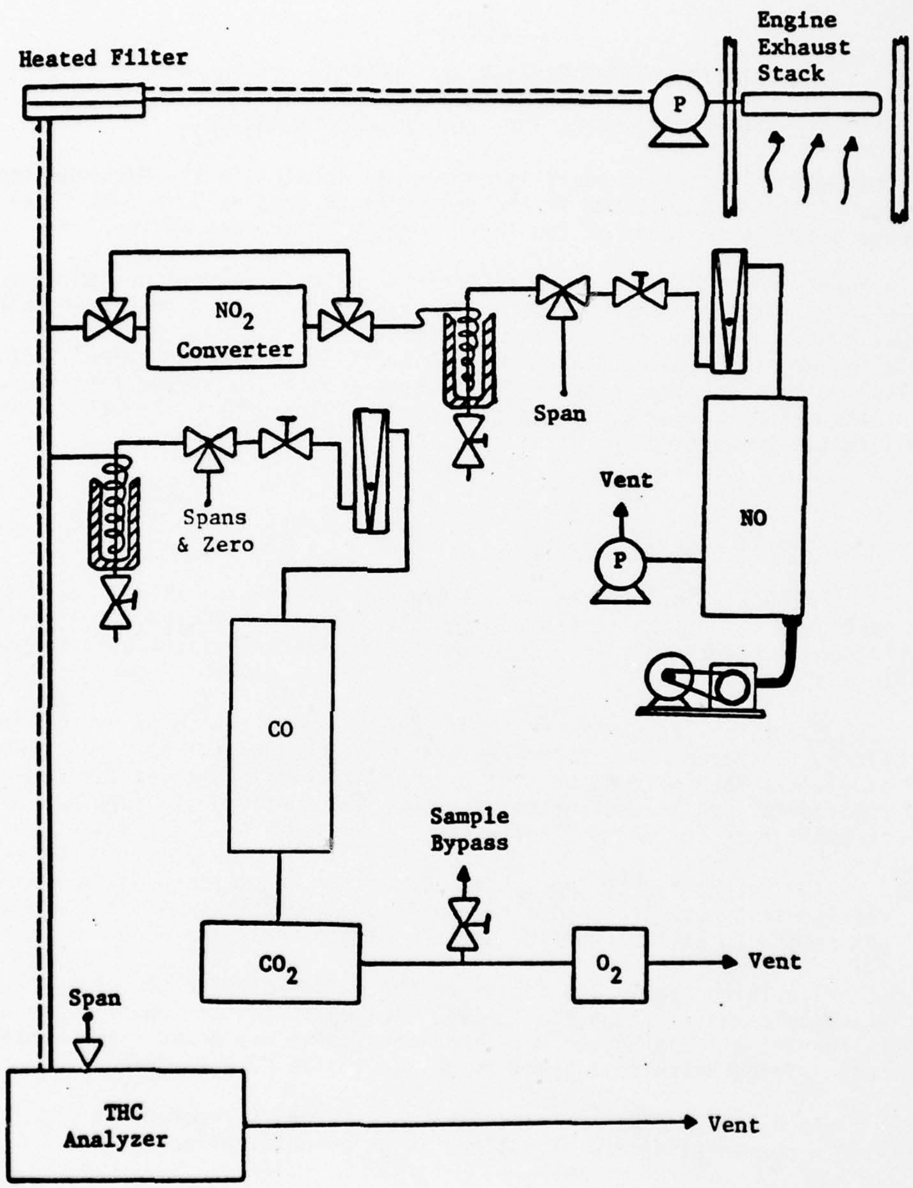


FIGURE B-1 MACKINAW EXHAUST ANALYSIS SYSTEM

B.2 INSTRUMENT DESCRIPTION

Total Hydrocarbons (THC)

Total hydrocarbons were continuously monitored using a Scott Model 215 heated total hydrocarbon analyzer. This instrument utilized a flame ionization detector and heated sample train, maintained at 300°F to prevent the condensation of high molecular weight hydrocarbons. The detector was fueled with a 40 percent blend of hydrogen in helium using blended air as the oxidant. The instrument was spanned using a Scott "close tolerance" (± 2.0% analysis) blend of 331 ppm propane in air and zeroed with a Scott blend of hydrocarbon free air (less than 0.1 ppm-C).

Carbon Monoxide (CO)

Carbon monoxide was continuously monitored using a Beckman Model 315A non-dispersive infrared analyzer with 0-500 and 0-1000 ppm ranges. This instrument was spanned with Scott "close tolerance" blends of CO in nitrogen (494 and 924 ppm CO in N_2) and zeroed with zero-grade nitrogen.

Oxides of Nitrogen (NO/NOx)

A Scott Model 125 chemiluminescence analyzer with a thermal converter was used for the analysis of nitric oxide (NO) and total oxides of nitrogen (NOx). The instrument was operated in the ranges of 0-1000 and 0-5000 ppm. The thermal converter was used to convert nitrogen dioxide (NO_2) to nitric oxide (NO) so that total oxides of nitrogen (NOx) could be measured. The converter was switched in and out of the system using solenoid valves to permit the selective operation of NO and NOx modes. Calibration of the instrument was provided by a Scott "close tolerance" blend of 981.2 ppm NO in nitrogen.

Oxygen (O_2)

Oxygen was continuously monitored using a Scott Model 150 paramagnetic oxygen analyzer. This instrument was operated in the 0-25% range and spanned with a Scott "close tolerance" blend of 9.89% O_2 in nitrogen and zeroed with zero-grade nitrogen.

Carbon Dioxide (CO_2)

An MSA Model Lira 300 non-dispersive infrared analyzer was used to measure CO_2 levels in the exhaust stream. The instrument was operated in the 0-15.0% range and spanned with a Scott "close tolerance" blend of 13.1% CO_2 in nitrogen. The instrument was zeroed with Scott zero-grade nitrogen.

The NO/NOx analyzer and the CO analyzer were mounted in instrument stands which sit on the floor under the instrument table. The NOx converter, refrigerator dryer and NO/NOx instrument vacuum pump were also located under the instrument table. The heated hydrocarbon instrument, the CO_2 analyzer and the oxygen analyzer were placed on the instrument table. Two strip chart recorders, a Texas Instrument 4 channel model and an Esterline Angus single channel model were also located on the top of the instrument table. The calibration/sample selector valves were grouped on the instrument stands for easy access to the instrument operator.

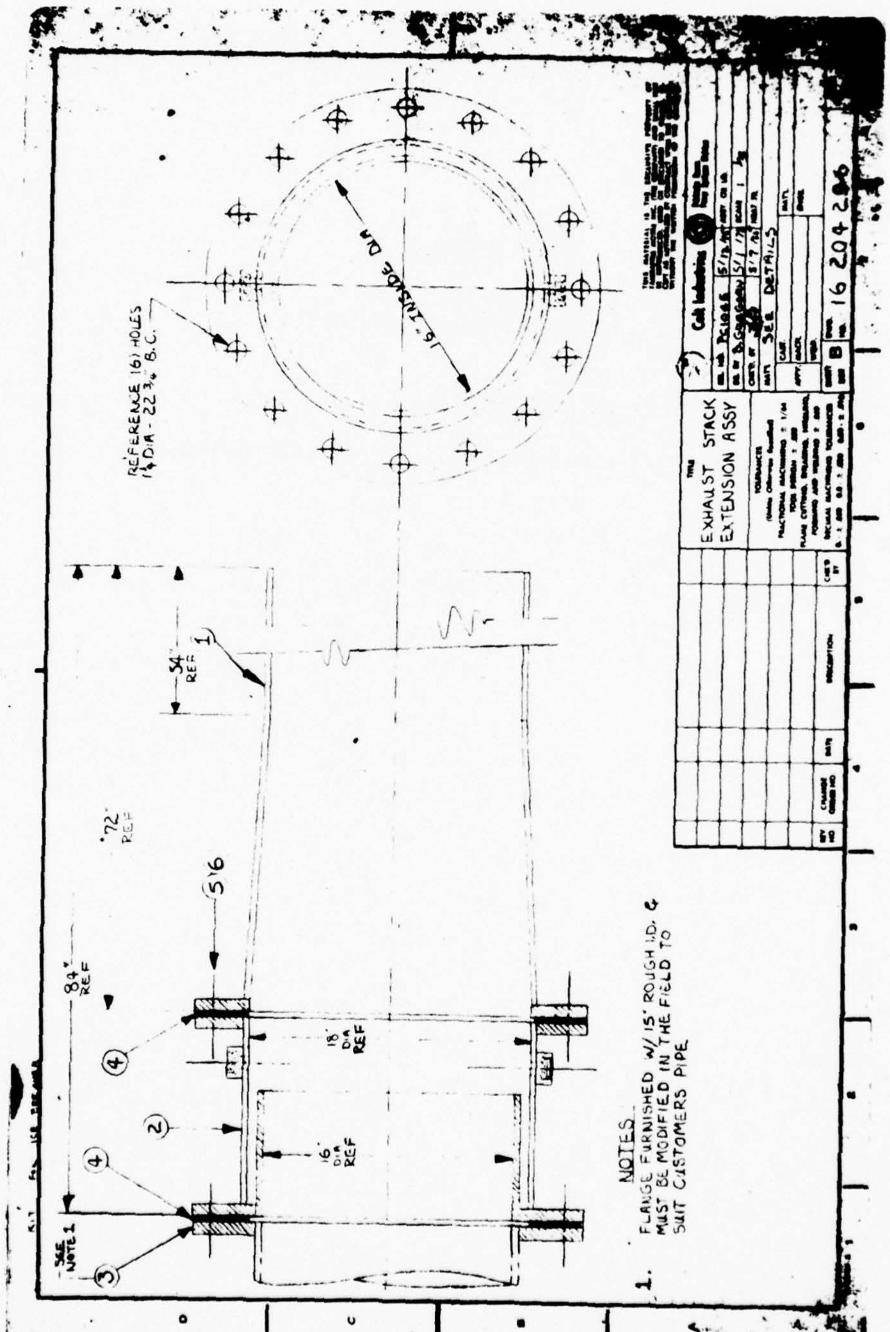
The operating environment for the instruments was typical of marine operation with the attendant mechanical vibrations from the engines and propellers and fluctuating power voltage levels due to load changes on the ship's generators. In general, the effects of the operating environment on the instruments was minimal. A pronounced ship resonance at 120 shaft RPM did cause a broadened signal trace from the oxygen analyzer due to mechanical vibration of its detector assembly. This, however, did not materially affect the instrument's performance.

In order to minimize the effect of the environment on the instrument readings, the instruments were zeroed and spanned at frequent intervals during each test run providing reference checks on instrument spans and zeros.

APPENDIX C

EXHAUST SMOKE MEASUREMENTS

1. EXHAUST STACK EXTENSION DRAWING 16 204 296.
2. SMOKE OPACITY CHART FROM 8-26-76 TEST RUN NUMBER 2.



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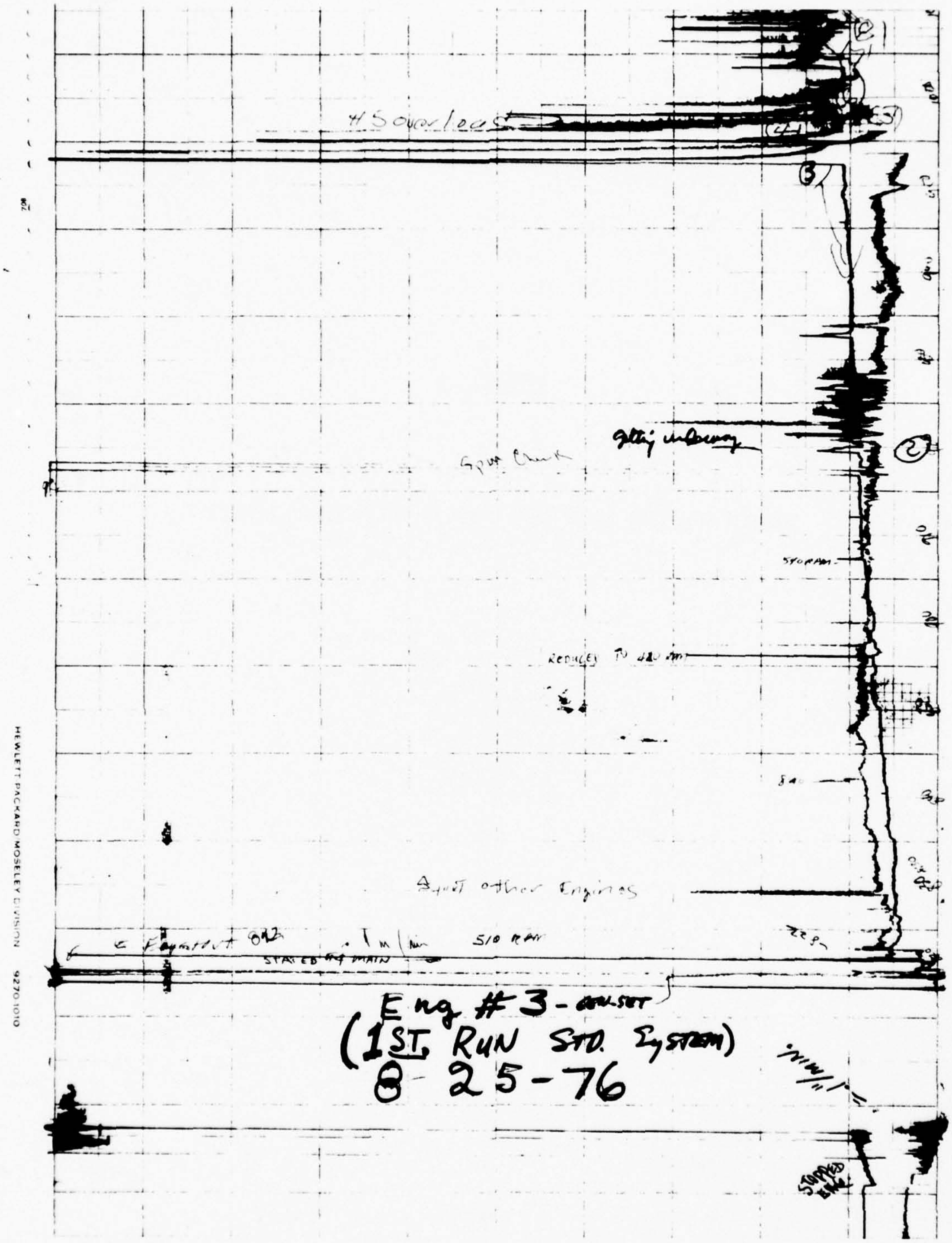
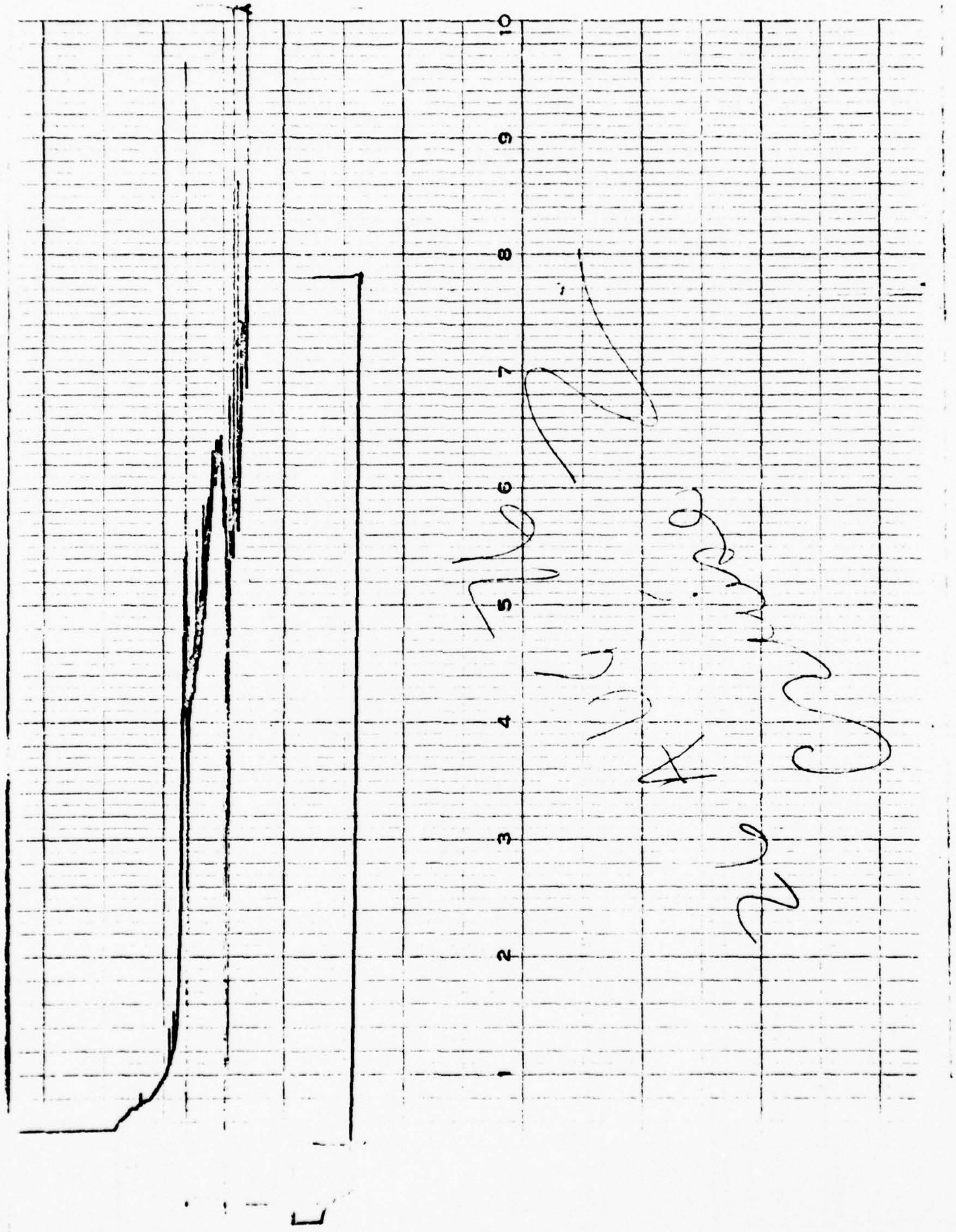

HEWLETT-PACKARD MOSELEY DIVISION
9270-1010
Spot Check
Spot other Engines
510 RPM
STARTED MAIN
Eng #3
(1ST RUN STD. SYSTEM)
8-25-76
STOPPED ENG

APPENDIX D

SAMPLE RAW TEST DATA FROM 8-26-76 TEST CRUISE NUMBER 2.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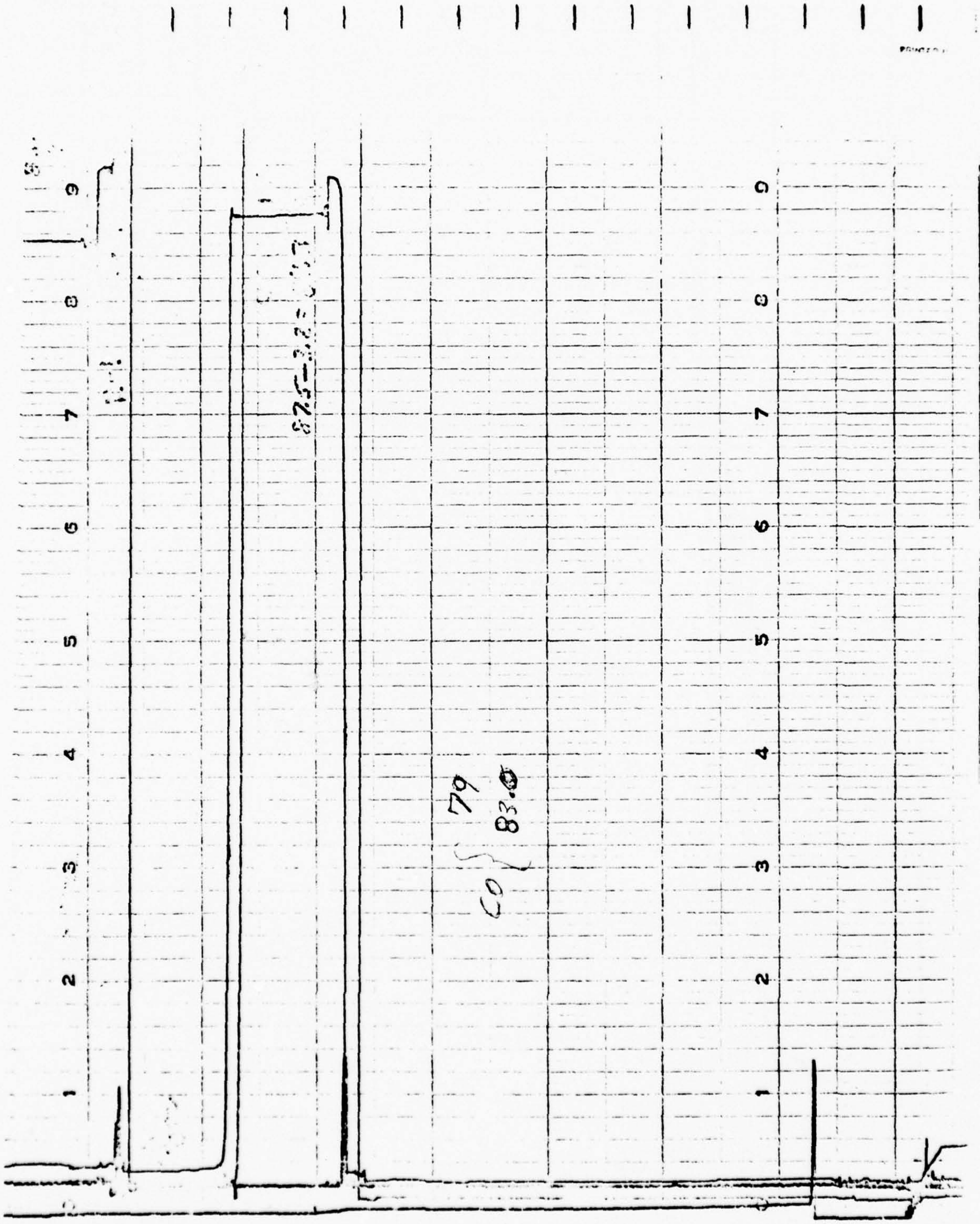
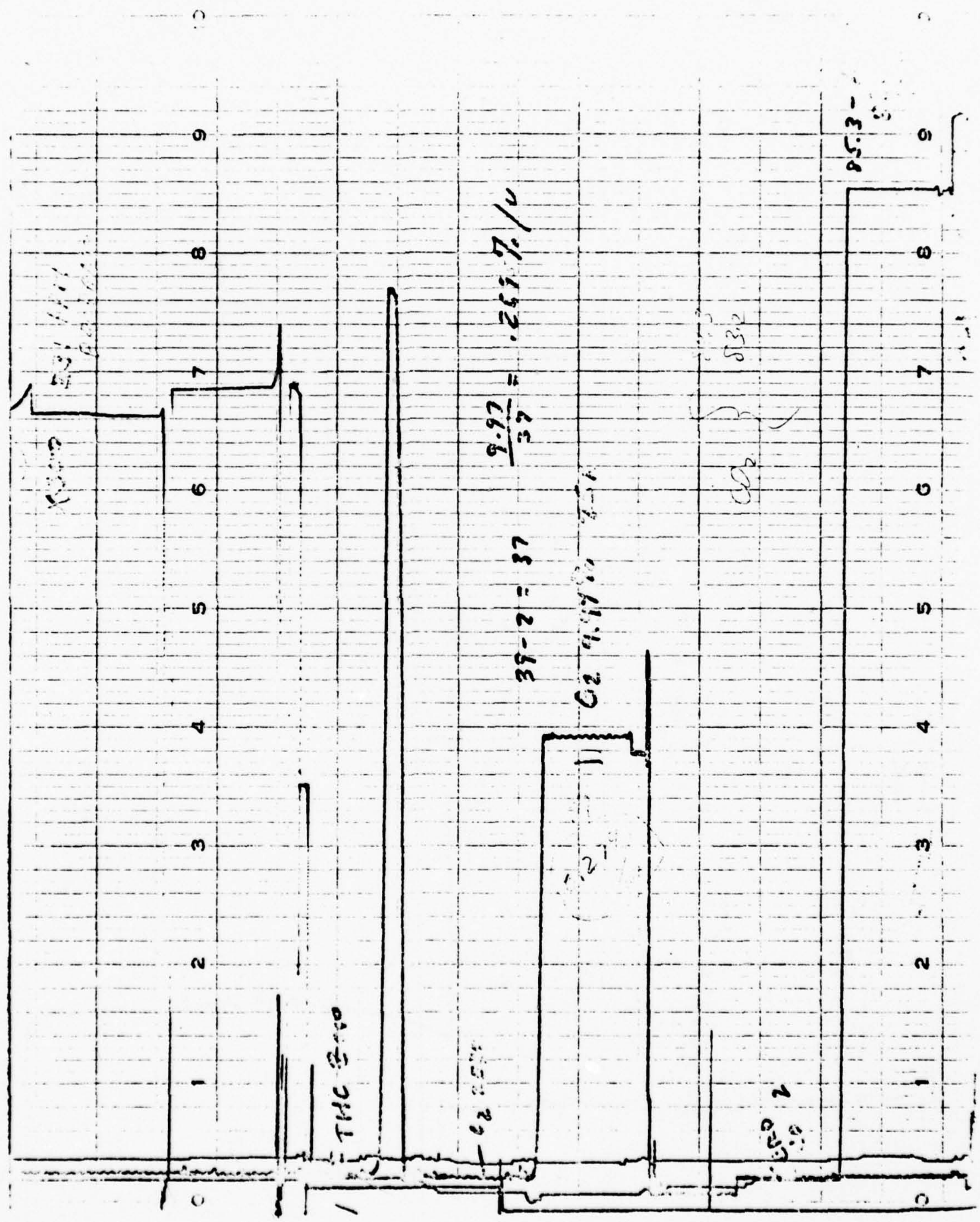
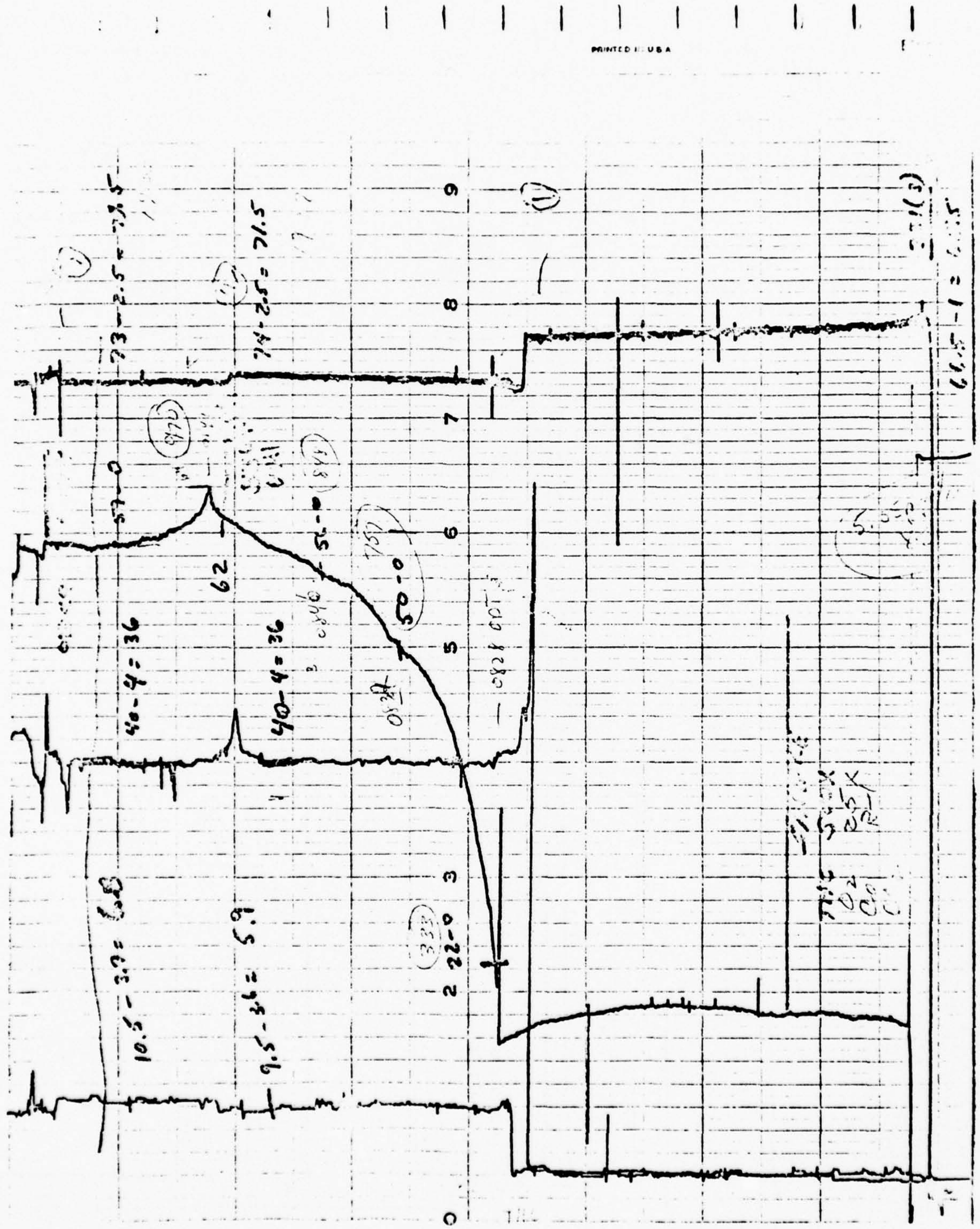
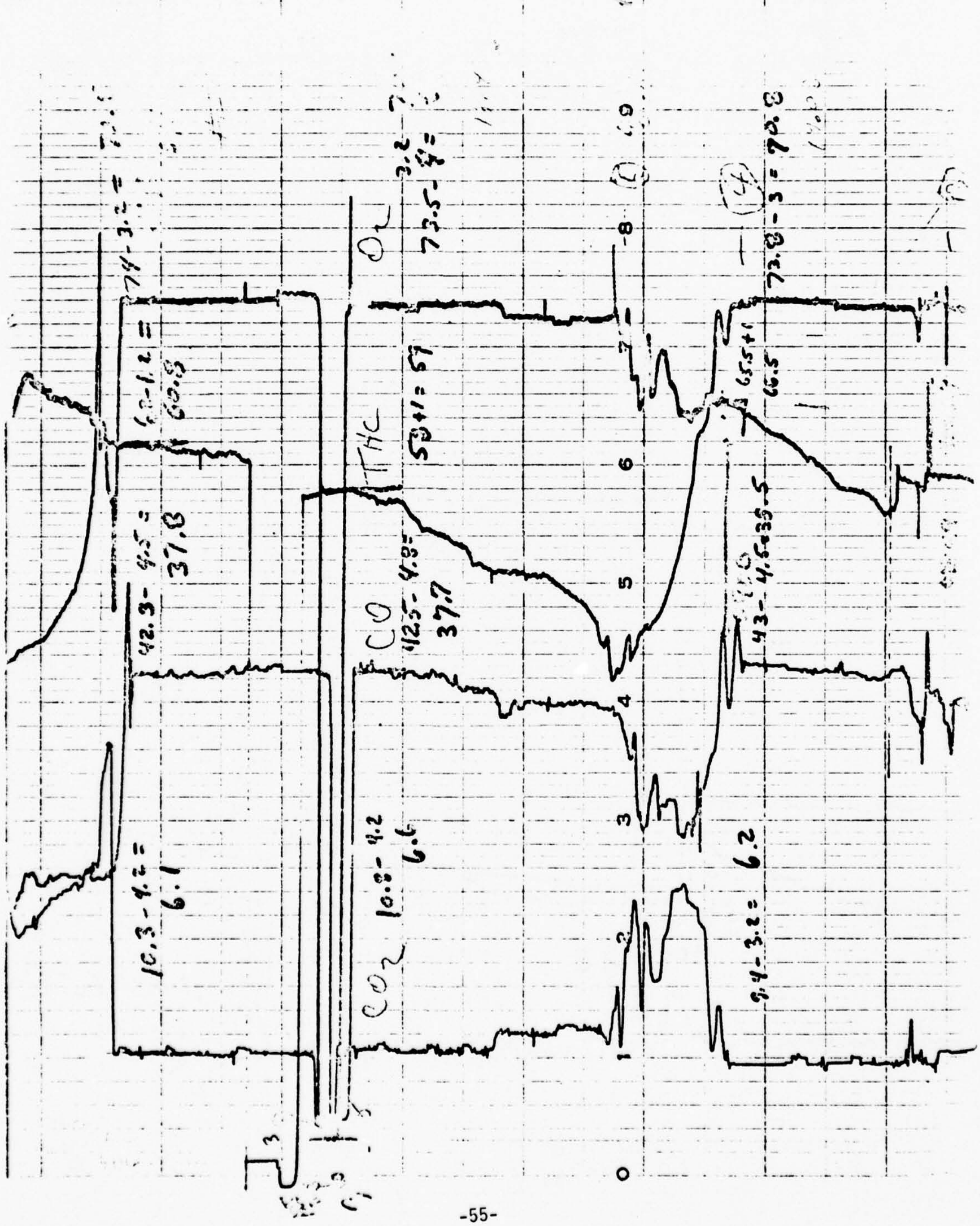
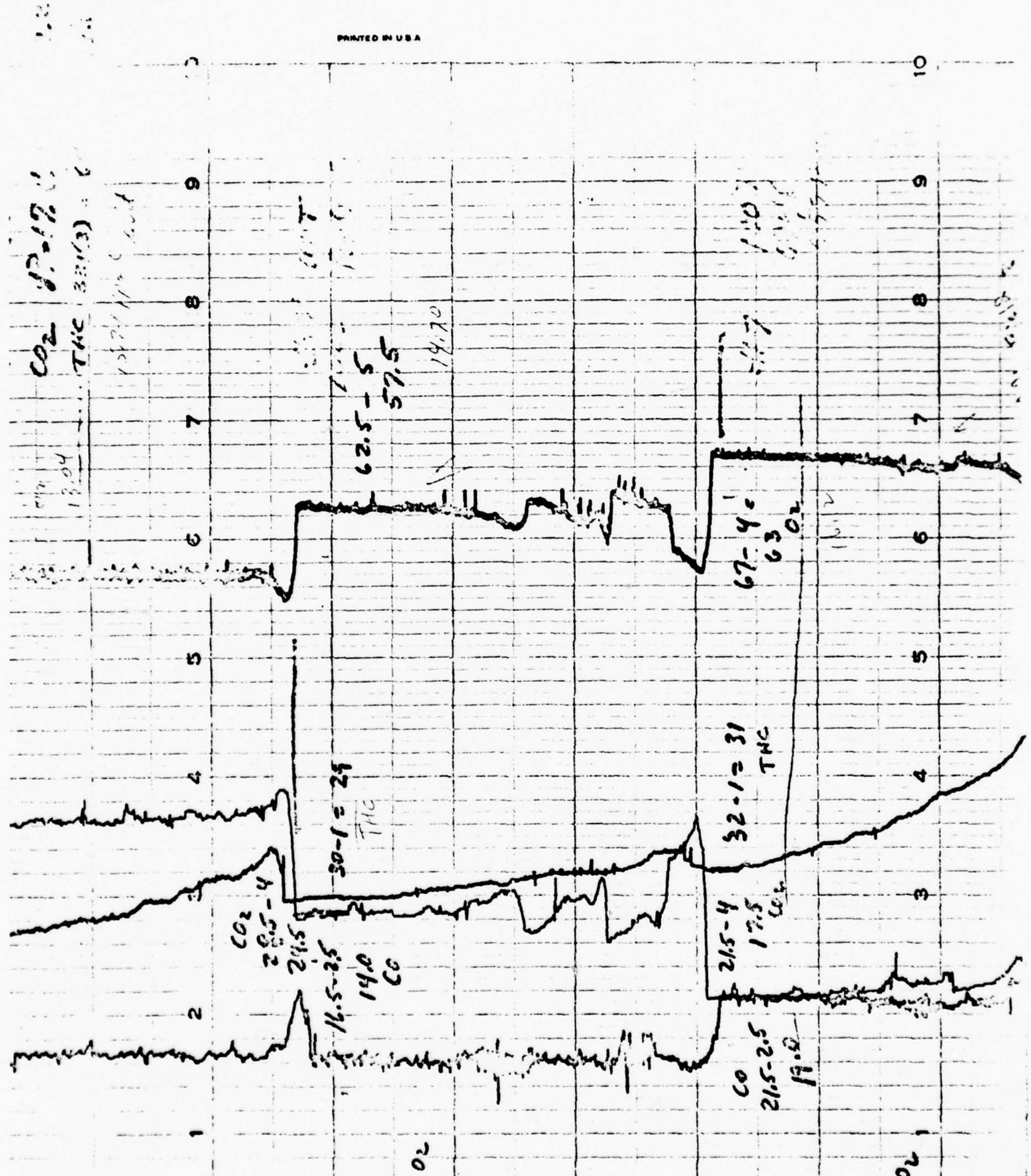
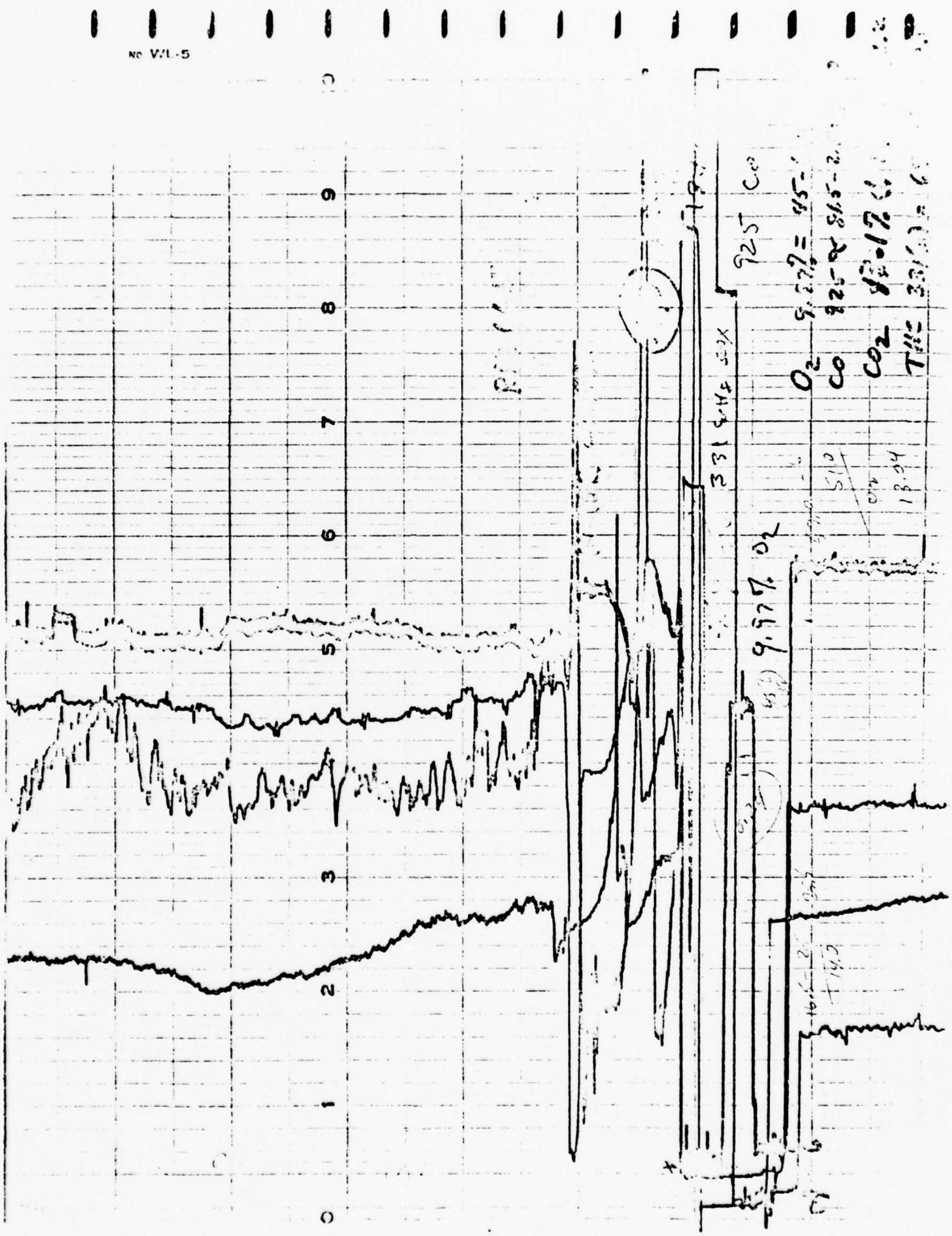


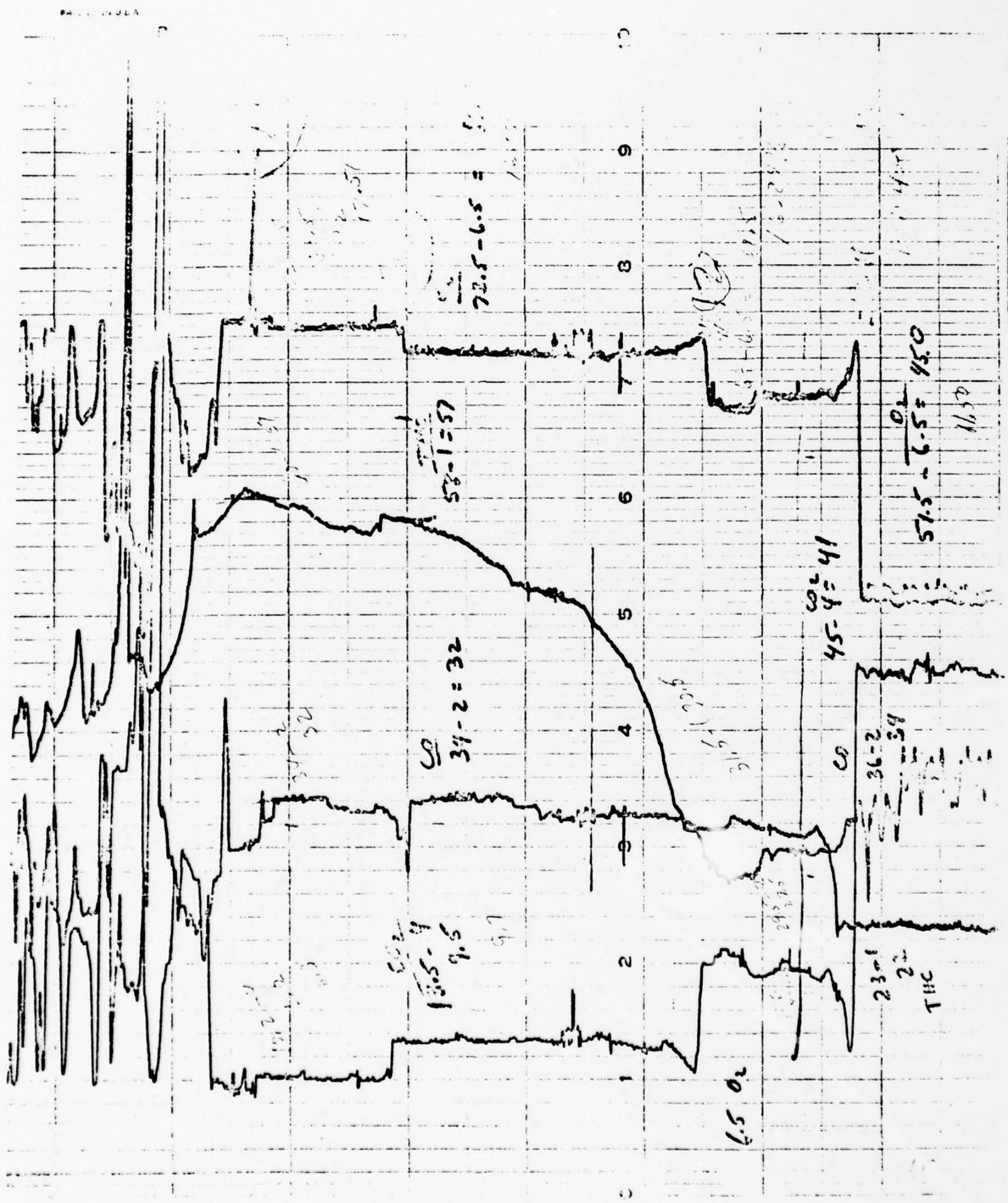


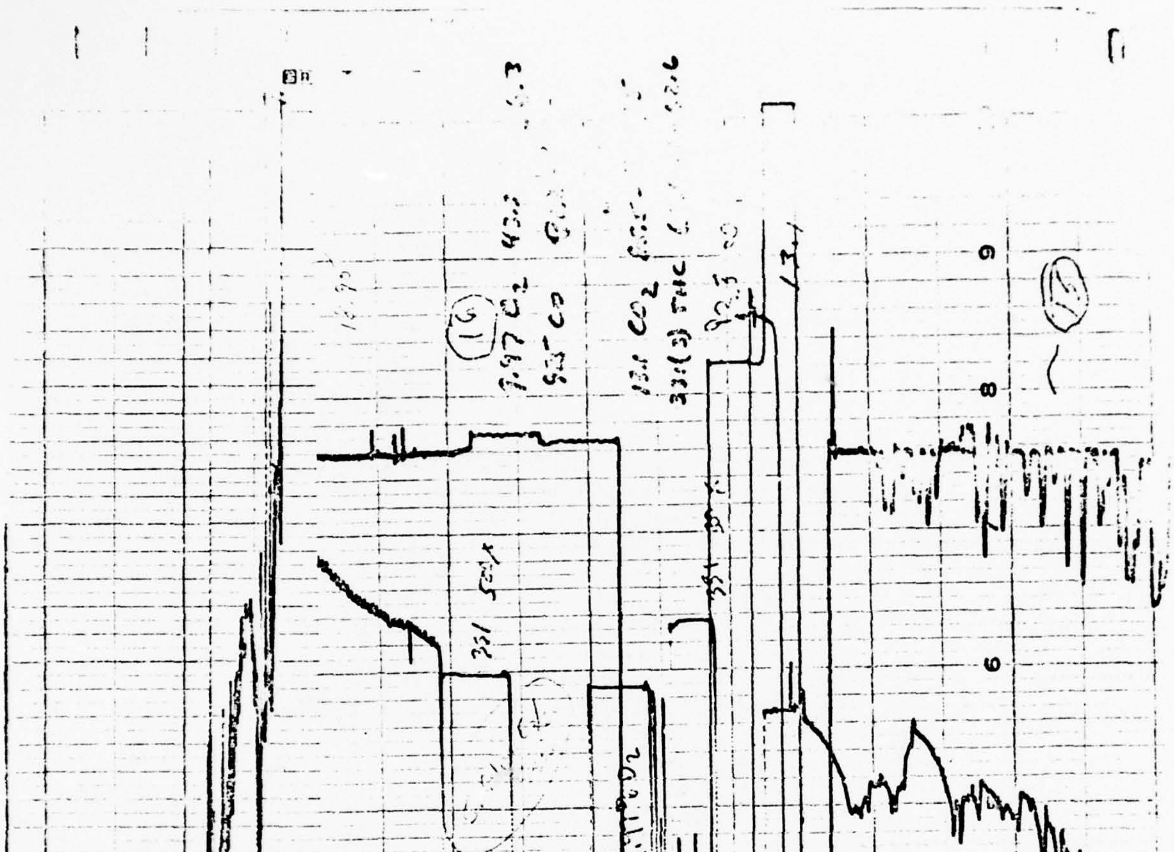


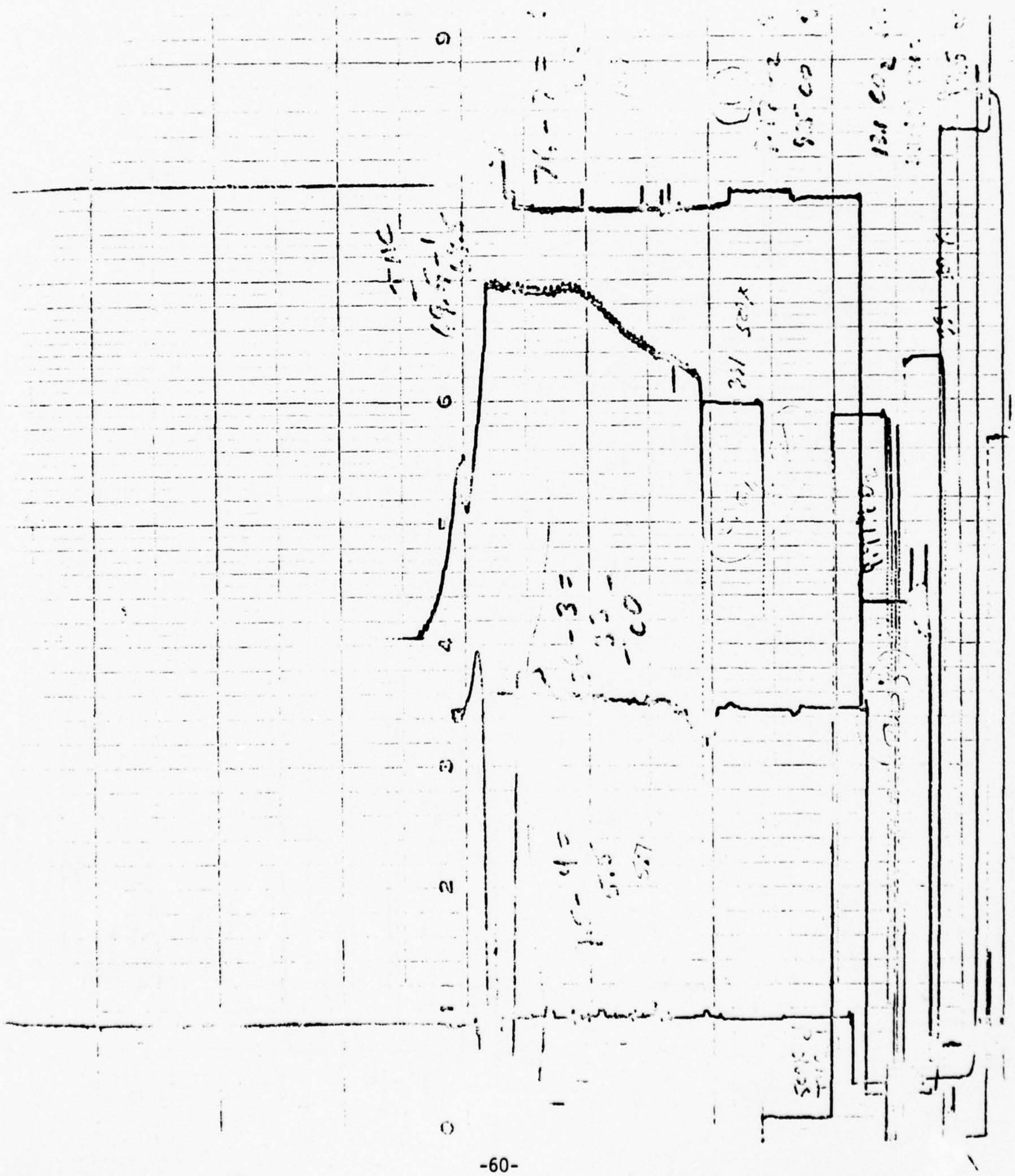

CO2
CO
THC
O2

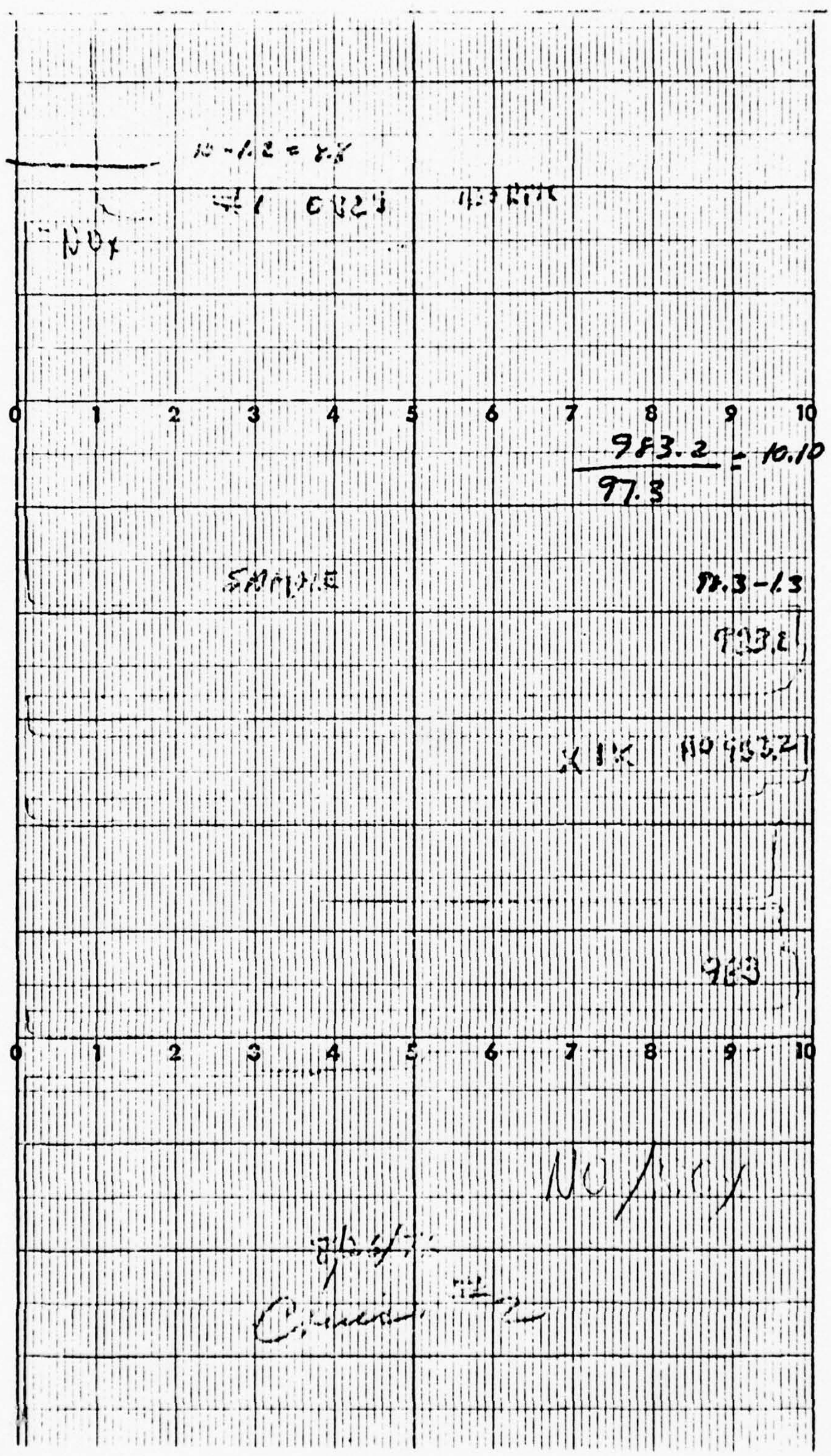

PRINTED IN U.S.A.
CO_2
THC
5 O_2
4 O_2
CO
THC

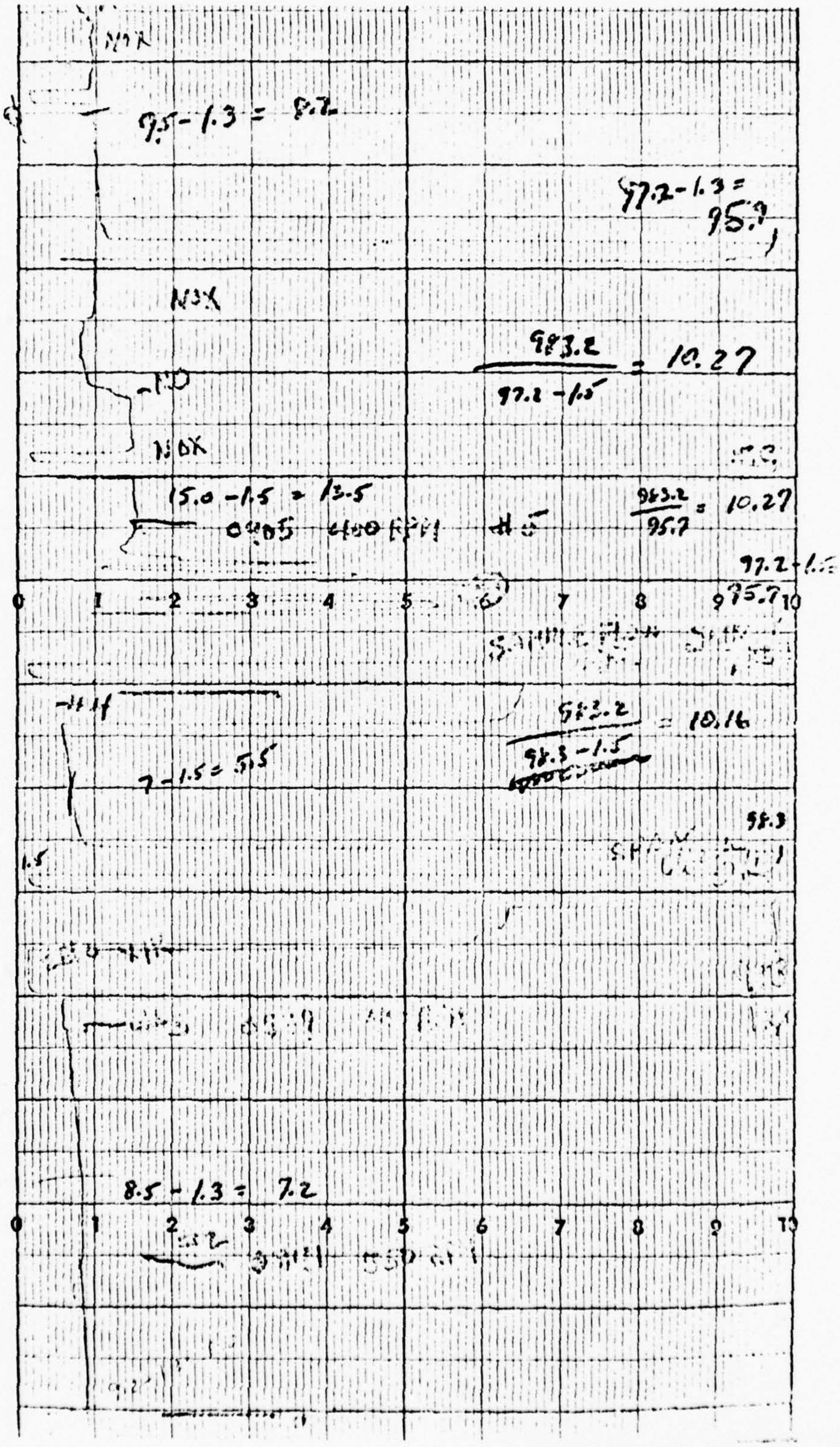


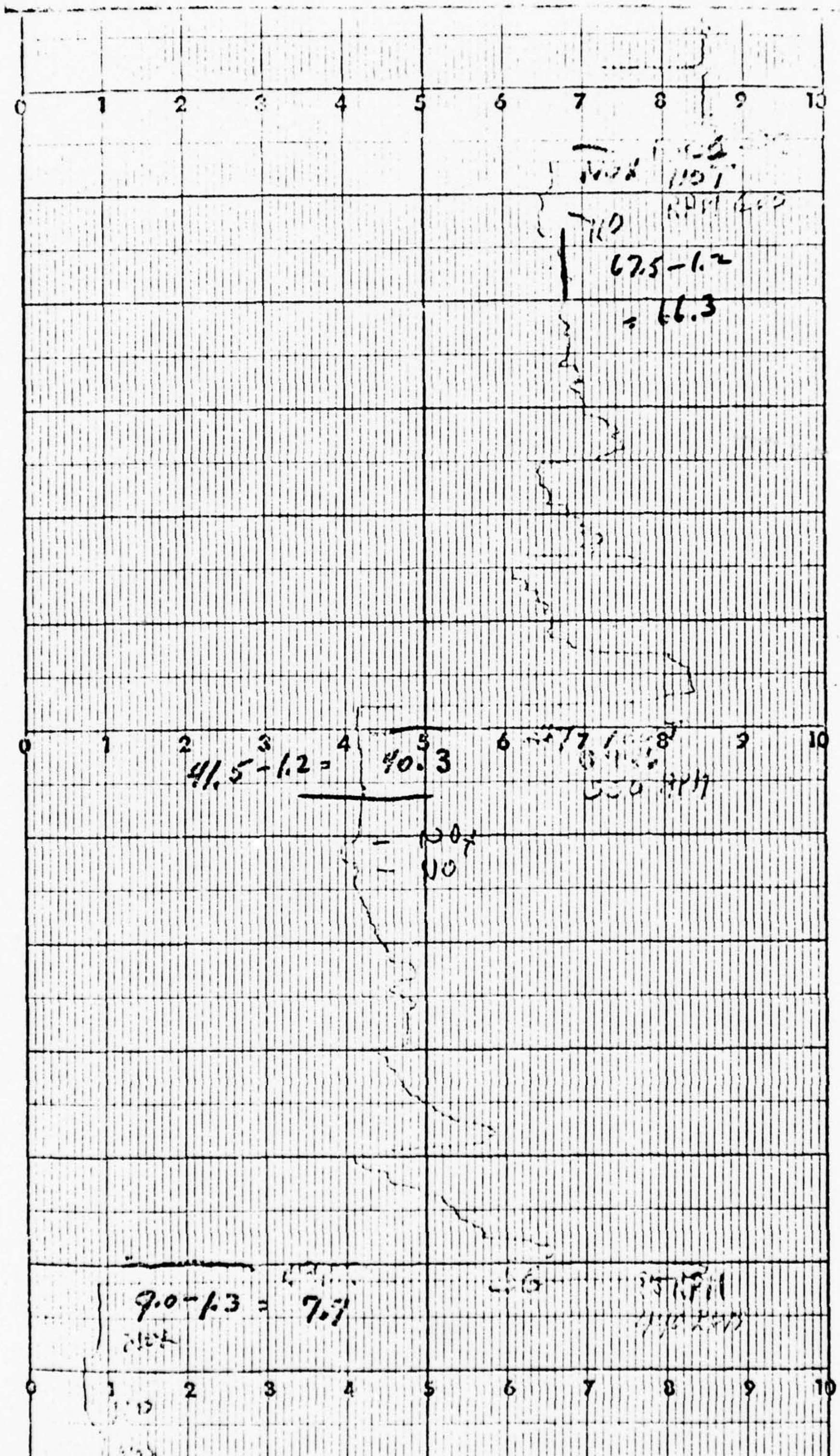


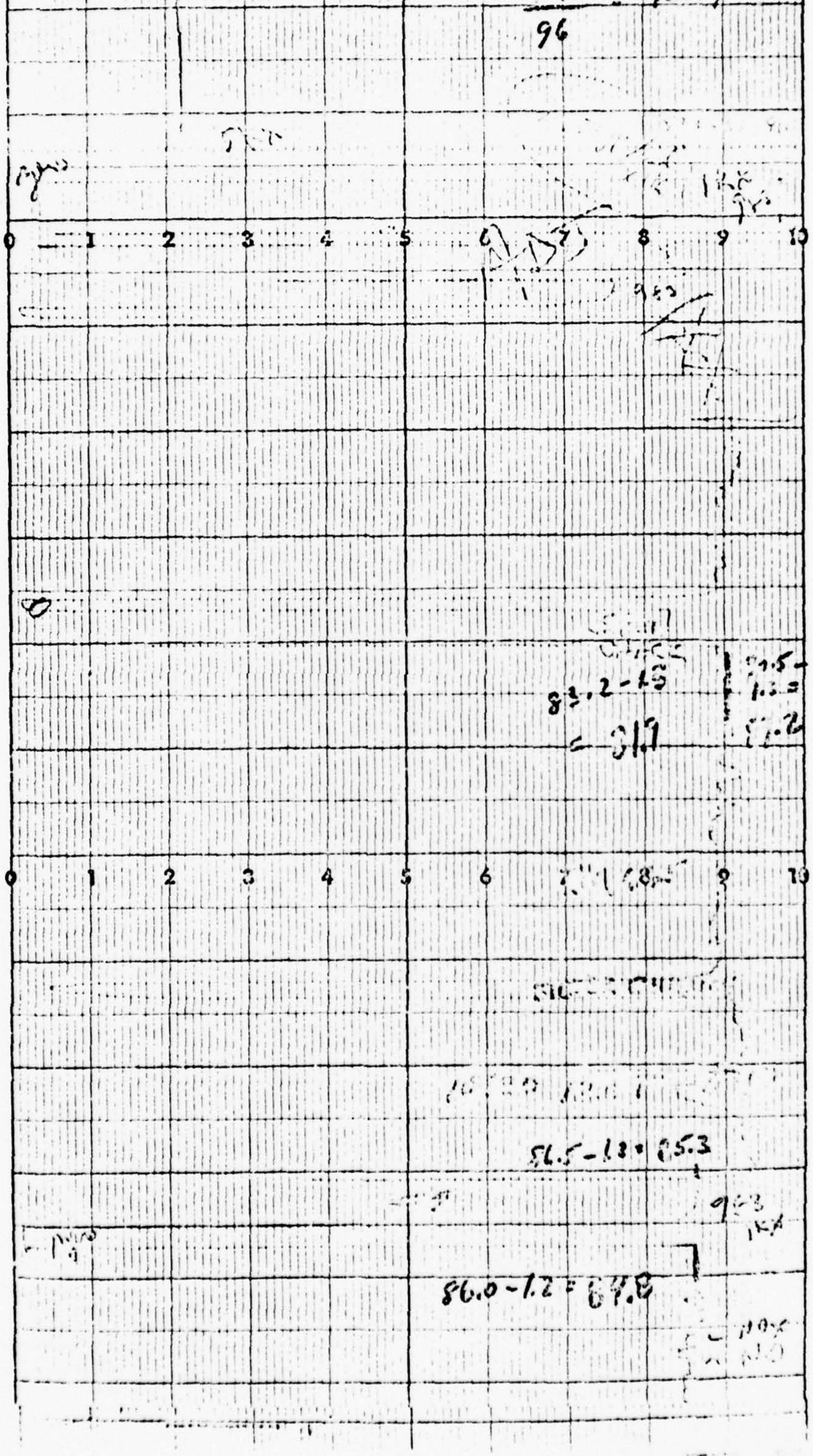


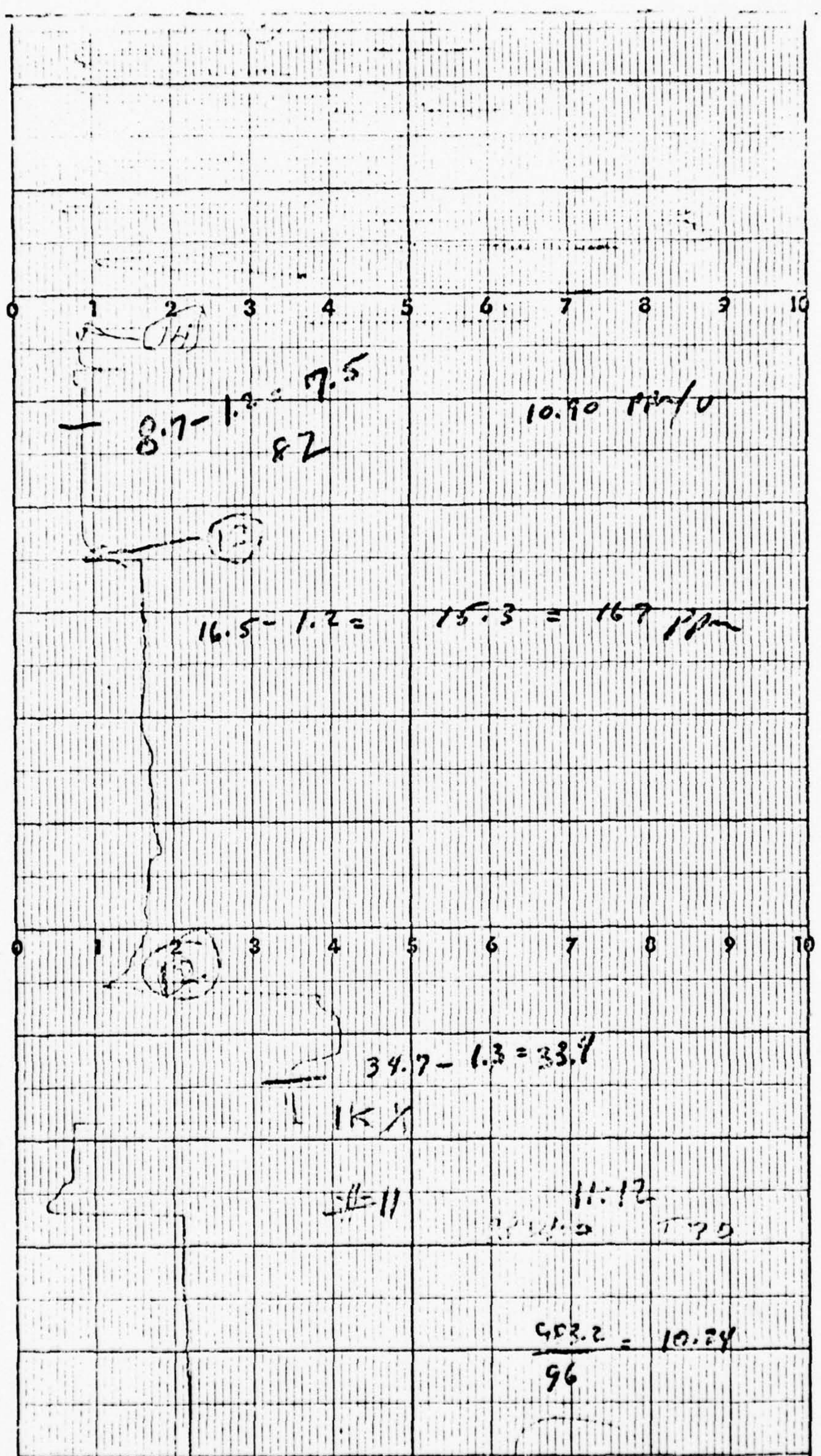


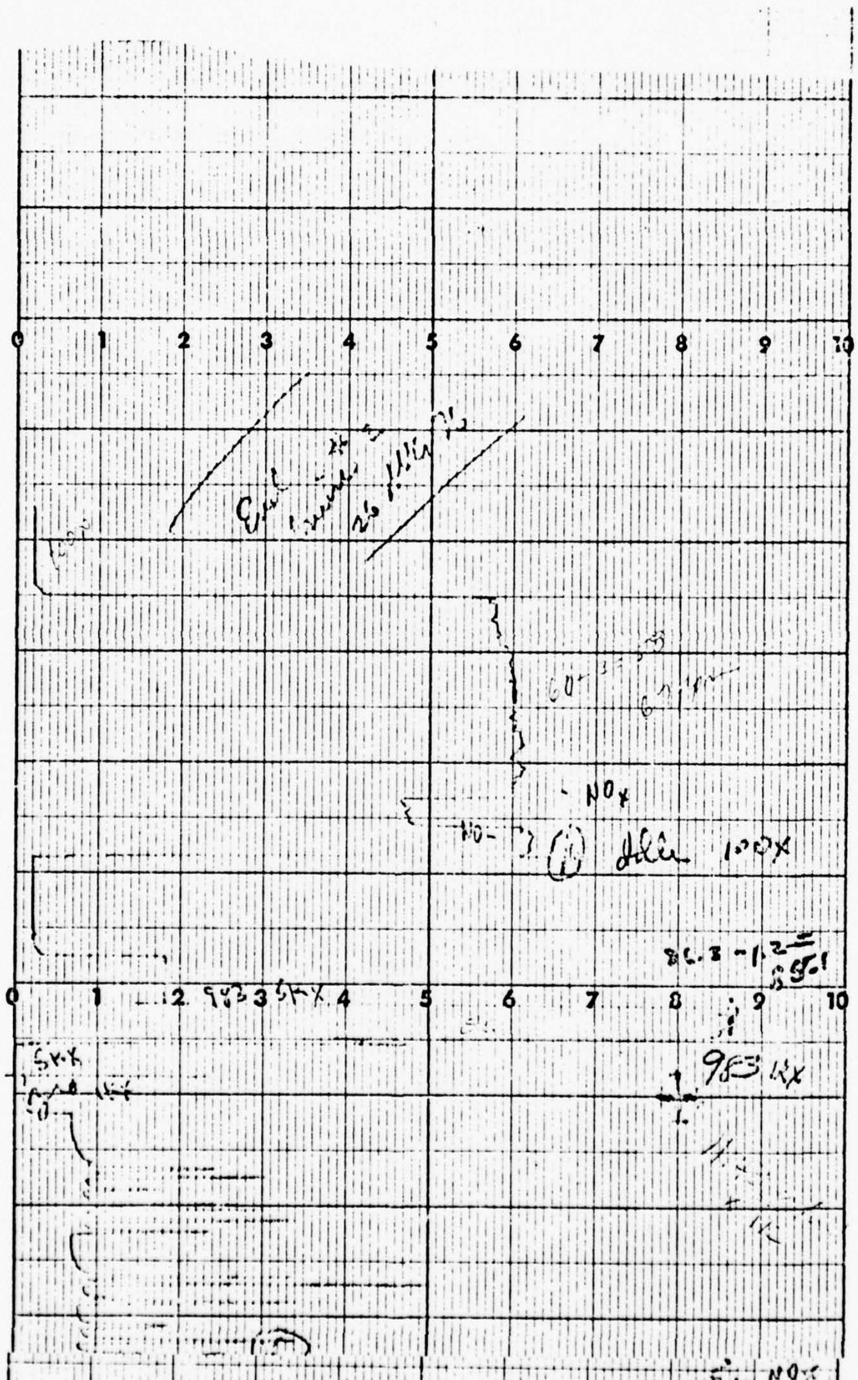

NOx
0 1 2 3 4 5 6 7 8 9 10
983.2 / 97.3 = 10.10
SAMPLE
97.3 - 1.3
983
0 1 2 3 4 5 6 7 8 9 10

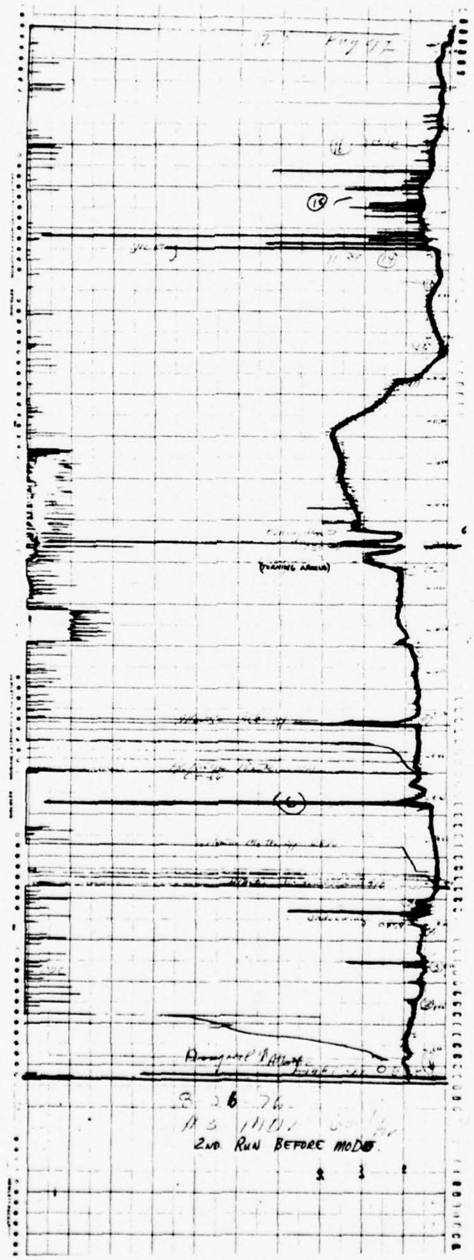

9.5 - 1.3 = 8.2
97.2 - 1.3 = 95.9
NOX
NO
983.2 / 97.2 - 1.5 = 10.27
15.0 - 1.5 = 13.5
983.2 / 95.7 = 10.27
97.2 - 1.5
0 1 2 3 4 5 6 7 8 9 10
983.2 / 98.3 - 1.5 = 10.16
7 - 1.5 = 5.5
98.3
1.5
8.5 - 1.3 = 7.2
0 1 2 3 4 5 6 7 8 9 10


0 1 2 3 4 5 6 7 8 9 10
67.5-1.2
= 66.3
41.5-1.2 = 40.3
9.0-1.3 = 7.7


96
0 1 2 3 4 5 6 7 8 9 10
0 1 2 3 4 5 6 7 8 9 10
86.0-1.2 = 84.8


0 1 2 3 4 5 6 7 8 9 10
16.5 - 1.2 =
0 1 2 3 4 5 6 7 8 9 10
34.7 - 1.3 =
11:12


0 1 2 3 4 5 6 7 8 9 10
NOx
0 1 2 3 4 5 6 7 8 9 10
NOx
NO


(TURNING AROUND)
8-26-76
2ND RUN BEFORE MODS.

TEST LOG

TEST: DOT smoke

ENGINE NO.

LOG NO.

DATE

POWER PAK

C. RING

LINERS

PISTONS

SPECIAL

ENGINE POWER OUTPUT | FUEL OIL | ENGINE AIR | ENGINE H₂O | ENGINE LUBE OIL | EXHAUST CYLINDER TEMP °F | EXHAUST GAS CONCENTRATION | SMOKE

Motor Rm - Amps can be read to ± 50 Amps (2000)
- Volts can be read to ± 25 volts (1000)
- RPM can be read to ± 10 rpm (1000)
- SRPM can be read to ± 5 rpm (200)

1/3 S - 40
2/3 S - 75
Std - 105
Full - 128
Flank - 150

} Plaque in M.R.

ICPM...AKER TEST SHEET

8-26-76 Eng. Mod. # 3808 1/3 Eng. Ser. #

Test Pt.	RPM Eng.	RPM Shaft	KW Eng.	KW Motor	Eng. on-line	Temp. H_2O In	Temp. H_2O Out	Temp. Oil In	Temp. Oil Out	Air	Exh. Cond.	Pres. Oil	Pres. Exh.	Pres. Other	Fuel Flow Time	Fuel Flow Vol.	Other
(1) 0828	400	idle	A - V														Warm-up
(2) 08-11	550	idle															
(3) 0844	600	idle															
(4) 0859	400	-70															← underway ahead-slow
(5) 0905	400	-35															
(6) 0928	400	-80															
(7) 0947	550	-100	1100	-550													
(8) 1006	600	110	1200	-600													
(9) ..25	coming about																
(10) 1030	665	120	1325	675													.943 Gal/Hr
(11) 11 10	400	70															
(12) 11 17	400	-40															
(13) 11 32	400	-20															← up channel
(14) 11 39	400	-															← Docking
(15) 1152	400	-															← line ashore
(16) 1207	400	- idle	for fuel check														
1212[32]	Off																

Mackinaw

[illegible]

8-26-76

Eng. # #3 Eng. Ser. #

Test Pt.	RPM Eng.	RPM Shaft	Amps Eng.	Amps Motor	Volts Eng.	On-Line	Temp. H.E. In	Temp. H.E. Out	Temp. S.W. In	Temp. S.W. Out	Air	Exh. Gas	Pres.	Pres. Exh.	Pres. Other	Fuel Flow Time	Fuel Flow Gal.	Other
0859	Underway			1050	380													
0900	410	65	550	~~[illegible]~~	~~[illegible]~~	209												
0905	410	43	200	200	220	44												
0910	410	40	100	150	200	20												
0915	410	40	130	150	200	26												
0920	410	40	130	150	200	26												
0925	410	40	130	150	200	26												
0928	440	50	700	1400	490	343												
0930	430	81	600	1100	450	370												
0935	430	80	550	1050	440	392												
0940	430	80	550	1050	440	392												
0945	430	80	540	1050	440	[illegible]												
0947	550	102	1000	1750	560	[illegible]												
0950	520	100	800	1600	530	[illegible]												
0953	530	100	850	1700	550	[illegible]												
0955	530	100	800	1700	550	[illegible]												
1000	530	100	830	1700	550	— [illegible]												
1005	595	110	1150	2100	600	[illegible]												
1010	595	110	1150	2100	600	[illegible]												
1015	595	110	1150	2100	600	[illegible]												
1020	595	110	1150	2100	600	[illegible]												
1025	590	110	1500	2600	590	[illegible]												
1030	645	120	1250	2400	680	[illegible]												
1035	665	122	1400	2600	690	966												
1040	665	122	1400	2600	680	952												
1045	660	122	1400	2500	690	[illegible]												
1050	665	122	1400	2550	680	[illegible]												

ICEBREAKER TEST SHEET

8-26-76

Eng. #3

Eng. Ser. #

Test Pt.	RPM		Amps		Volts	Eng.	Temp.						Pres.			Fuel Flow		Other
	Eng.	Shaft	Eng.	Motor		On-line	H_2O In	H_2O Out	Oil In	Oil Out	Air	Exh. Comp.	Oil	Exh.	Other	Time	Gal.	
1055	665	122	1400	2600	680	952												
1100	660	120	1400	2550	680	952												
1105	665	122	1375	2550	680	[illegible]												
1110	420	79	350	750	420	147												
1115	[illegible]	75	480	900	410	147												
1118	420	55	150	[illegible]	300	[illegible]												
1120	420	53	250	500	300	75												
1125	420	52	250	500	300	[illegible]												
1130	420	51	250	500	300	75												
1133	420	38	50	100	190	[illegible]												
1135	420	35	50	100	180	[illegible]												
1139	420	0	0	0	0	0												
1142	460	80	800	1600	450	365												
1143	420	55	300	700	200	60												
1145	530	90	1200	2100	500	[illegible]												
1146	420	65	600	1000	400	[illegible]												

BEST AVAILABLE COPY

APPENDIX E

TEST SHIP DESCRIPTION AND ENGINE TEST PROCEDURE.

The USCGC Mackinaw (WAGB-83) has six 2000 horsepower main diesel engines manufactured by Fairbanks Morse in 1943. Each main diesel engine drives a DC electric generator. The generator outputs of the main engines are connected to DC electric 10,000 hp propulsion motors. Two stern propulsion motors drive the two stern propellers, 14 feet diameter and 10.7 tons each; and a third propulsion motor drives the bow propeller, 12 feet diameter and 4.2 tons. The ship is 290 feet long, has a beam of 74.5 feet and a full load draft of 19 feet 2¼ inches. The displacement is 5,252 tons and has a maximum speed of 18.7 mph. The Mackinaw personnel allowance consisted of 10 officers and 97 enlisted men.

The Mackinaw sailed from its home port of Cheboygan, Michigan during the reported engine tests. Two test runs each were made before and after engine modifications during the period of August 23, 1976 and September 2, 1976. The tests were conducted on the main diesel engine #3 before and after modifications to reduce smoke and emissions from that engine. In normal ship operation, the outputs of anywhere from one to three main diesel engines are connected to one stern propulsion motor. It was in the two engine configuration that the main diesel #3 was tested.

Two test runs were made on the unmodified engine and two test runs were made on the modified engine. Each test run consisted of normal engine operation prior to leaving the mooring (approximately 30 minute idle warm-up) and underway at various steady loads. The power settings tested corresponded to the following ship operating modes.

Ship Operating Mode	Shaft RPM	Approximate Engine #3 RPM	Approx. % Load
Engine Start - Slow Idle	-	440	0
Fast Idle	-	500	0
Slow Ahead	30	440	3
One-Third	40	440	5
Half	60	440	10
Two-Thirds	80	440	20
Cruise Range	100	520	40
Cruise Range	110	600	50
Cruise Range - Full	120	700	70

In order to coordinate the emissions data, engine data, operating data and smoke data which were taken simultaneously but in different parts of the ship, a unique reference number was used to indicate each engine operating mode during a test. The numbers were serially marked in chronological order of test point occurrence along with the time of the clock. Table 1 outlines the test schedule and includes the sample time and data point reference number along with the approximate engine RPM and ship's motor shaft RPM.

TABLE E-1

MACKINAW ENGINE #3 TEST SCHEDULE

	Time (EDT)	Reading No.	Log Office Shaft RPM	Log Office Engine RPM	Remarks
Cruise 1 8/25/76	0831	1	0	500	Start
	0918	2	V*	420	Getting Underway
	0934	3	50	440	Slow Ahead
	0955	4	100	620	
	1026	10	120	750	Full
	1035	11	-	-	Turn
	1045	12	120	700	Full
	1110	13	85	520	Slow Cruise
	1116	14	50	440	Slow
	1207	16	-	440	Slow
Cruise 2 8/26/76	0828	1	0	440	Start Engine
	0841	2	0	550	Fast Idle
	0849	3	0	440	Slow Idle
	0859	5	35	440	Slow Ahead
	0929	6	80	450	2/3
	0947	7	100	550	
	1011	8	115	600	
	1030	10	120	650	
	1109	11	70	400	
	1117	12	40	400	
	1120	13	-	400	Slow
	1207	16	0	440	Idle
Cruise 3 9/1/76	0809	1	0	500	Fast Idle
	0821	2	0	440	Slow Idle
	0835	4	45	420	Slow Ahead (Engine 3 only on STBD Motor)
	0905	5	40	440	Slow
	0933	6	60	440	1/2
	0956	7	80	440	
	1012	8	100	520	
	1042	9	110	600	
	1109	10	120	700	Full

*V - Variable

TABLE E-1 (Continued)

MACKINAW ENGINE #3 TEST SCHEDULE

	Time (EDT)	Reading No.	Log Office Shaft RPM	Log Office Engine RPM	Remarks
Cruise 4	0805	1	0	500	Fast Idle
9/2/76	0816	2	0	440	Slow Idle
	0834	3	0	500	Fast Idle
	0845	5	30	410	Slow Ahead
	0855	6	40	420	
	0921	7	60	420	1/2
	0947	8	80	430	
	1012	9	100	540	
	1038	10	110	610	
	1100	11	120	660	Full

APPENDIX F

TABLE OF TEST RESULTS OF THE FOUR CRUISES AND

THE CALCULATED EMISSIONS OF THESE CRUISES

TABLE F-1

DIESEL ENGINE EXHAUST EMISSION CONCENTRATIONS
USCGC MACKINAW (WAGB-83)
CHEBOYGAN, MICHIGAN

Cruise Number 1 Test Date August 25, 1976

						Concentrations - Dry				Conc. Wet
Test Point Number	Begin Time	Engine RPM	Load KW	Seconds For 25# Fuel	Smoke % Opacity	CO (ppm)	CO_2 (%)	O_2 (%)	NOx (ppm)	THC (ppm-C)
1	822	480	0	1049.4	6	335	0.70	19.44	+	873.5
2	919	400	0	1166.0*	7	344	0.62	19.17	+	828.3
3	927	410	130	859.4	8	227	1.40	18.36	+	609.9
10	1026	735	1060*	143.2	22	290	5.30	13.10	1049.5	-
12	1035	655	910	165.1	17	193	5.40	13.23	1106.4	-
13	1110	655	340*	401.6*	20	163	2.22	17.28	428.2	283.9
14	1117	480	250	514.3*	17	265	1.75	17.96	307.4	612.5
16	1134	400	0	1166.0*	10	335	0.62	17.17	61.5	814.2

* Estimate

\+ Reading invalid, NOx system leaking

TABLE F-2

DIESEL ENGINE EXHAUST EMISSION CONCENTRATIONS
USCGC MACKINAW (WAGB-83)
CHEBOYGAN, MICHIGAN

Cruise Number 2 Test Date August 26, 1976

						Concentrations - Dry				Conc. Wet
Test Point Number	Begin Time	Engine RPM	Load KW	Seconds For 25# Fuel	Smoke % Opacity	CO (ppm)	CO_2 (%)	O_2 (%)	NOx (ppm)	THC (ppm-C)
1	828	405	0	1391.3	9	328	0.60	19.17	76.4	924.2
2	841	550	23	1240.5*	8	322	0.85	18.90	56.0	894.0
3	849	410	0	1391.5	5	350	0.60	19.17	51.0	992.3
5	905	410	26	1211.6	7	338	0.85	19.04	87.0	910.4
6	928	420	242	550.6	8	148	2.35	17.15	414.7	474.3
7	947	525	447	320.4	8	115	3.35	15.80	768.7	452.4
8	1006	580	690	224.5	12	126	4.40	14.18	983.0	397.8
10	1030	650	959	158.3	25	314	5.70	12.42	1078.9	346.5
11	1110	410	215*	575.0*	6	247	2.05	17.15	348.1	485.1
12	1117	410	65	924.7	3	292	1.25	18.09	163.8	923.4
13	1132	410	20	1260.0*	3	292	0.80	18.63	82.5	973.5
16	1207	410	0	1391.5	4	314	0.60	18.63	66.3	1144.5

* Estimate

TABLE F-3

DIESEL ENGINE EXHAUST EMISSION CONCENTRATIONS
USCGC MACKINAW (WAGB-83)
CHEBOYGAN, MICHIGAN

Cruise Number 3 Test Date September 1, 1976

Test Point Number	Begin Time	Engine RPM	Load KW	Seconds For 25# Fuel	Smoke % Opacity	Concentrations - Dry: CO (ppm)	Concentrations - Dry: CO_2 (%)	Concentrations - Dry: O_2 (%)	Concentrations - Dry: NOx (ppm)	Conc. Wet: THC (ppm-C)
1	805	490	0	1270.0*	5	280	0.95	19.71	125.5	176.6
2	821	410	0	1600.0	4	290	0.80	19.84	117.1	171.6
4	835	410	380	391.4	6	150	3.40	15.93	1253.3	95.7
5	905	407	50	1435.0	4	216	1.00	18.50	244.4	130.4
6	933	403	136	878.3	4	170	1.70	17.42	447.3	118.8
7	952	422	270	530.3	4	127	2.65	16.20	903.4	105.6
8	1011	521	520	296.7	10	108	3.82	15.26	1169.1	90.8
9	1040	603	768	209.8	17	148	4.62	14.42	1320.0	100.7
10	1102	667	1030	153.0	18	296	5.57	12.88	1387.7	128.7

* Estimate

TABLE F-4

DIESEL ENGINE EXHAUST EMISSION CONCENTRATIONS
USCGC MACKINAW (WAGB-83)
CHEBOYGAN, MICHIGAN

Cruise Number 4 Test Date September 2, 1976

						Concentrations - Dry				Conc. Wet
Test Point Number	Begin Time	Engine RPM	Load KW	Seconds For 25# Fuel	Smoke % Opacity	CO (ppm)	CO_2 (%)	O_2 (%)	NOx (ppm)	THC (ppm-C)
1	805	510	0	1220.0*	4	304	0.90	19.73	122.9	155.7
2	816	410	0	1600.0*	3	335	0.80	19.83	110.2	160.4
3	834	510	0	1220.0*	3	312	0.91	19.73	111.6	164.0
5	847	407	100	1125.0*	2	232	1.35	19.19	294.0	157.5
6	855	407	46	1434.0*	2	264	1.02	19.89	205.6	152.3
7	921	405	128	925.0*	7	188	1.55	19.06	387.5	157.2
8	947	415	160	802.0*	8	157	1.98	18.41	533.5	159.0
9	1010	529	490	316.0*	9	99	3.50	16.30	1022.0	76.7
10	1038	540	435	345.0*	7	107	3.38	16.87	938.2	74.1
11	1054	641	897	179.0*	15	282	5.00	13.51	1273.0	145.5

* Estimate

PROGRAM EGREM - VERSION 2/26/74

FIXED INPUT DATA-

ENGINE TYPE	-38D8 1/8
SERIAL NUMBER	-B33681
NUMBER OF STROKE PER CYCLE	2
CYLINDER DISPLACEMENT-INCH3	1037.0
NUMBER OF CYLINDER	10
LOG NUMBER	1
LOG DATE	8/ 25/ 76
DIESEL FUEL SHOP NUMBER	2
DIESEL FUEL H.H.V.-BTU/LB	19496.
DIESEL FUEL L.H.V.-BTU/LB	18318.
DIESEL FUEL ATOMIC H/C RATIO	1.77
DIESEL FUEL SULFUR-PCT-WEIGHT	0.24
NO CORRECTION FACTOR	0.003360

VARIABLE INPUT DATA-						
LOG LINE	1	2	3	10	12	13
ENGINE SPEED-RPM	480.0	400.0	410.0	735.0	655.0	655.0
ENGINE LOAD-BHP	1.0	1.0	130.0	1060.0	910.0	340.0
BAROMETER PRESSURE-INCH HG	30.12	30.12	30.12	30.11	30.11	30.11
DIESEL QUANTITY-LB	25.0	25.0	25.0	25.0	25.0	25.0
TIME-SEC.	1049.4	1166.0	859.4	143.2	165.1	401.6
VAP. PRESS. H2O (SUCTTEMP)-PSIA	0.272	0.272	0.310	0.310	0.350	0.350
RELATIVE HUMIDITY-PERC.-ORI.T.	84.0	84.0	80.5	80.5	77.0	77.0
HYDROCARBONS-PPM-VOL.	874.	828.	610.	0.	0.	284.
METHANE-PPM-VOL.	0.	0.	0.	0.	0.	0.
OXIDES OF NITROGEN-PPM-VOL.	0.	0.	0.	1050.	1106.	428.
CARBON MONOXIDE-PPM-VOL.	335.	344.	227.	290.	193.	163.
CARBON DIOXIDE-PPM-VOL.	0.70	0.62	1.40	5.30	5.40	2.22
OXYGEN-PERCENT-VOL.	19.44	19.17	18.36	13.10	13.23	17.28
PARTICULATE MATTER-GR/FT3	0.0	0.0	0.0	0.0	0.0	0.0
BOSCH SPOT NUMBER	6.00	7.00	8.00	22.00	17.00	20.00

CALCULATED DATA-						
BMEP-PSI	0.08	0.10	12.11	55.07	53.05	19.82
BS DIESEL FUEL CONS.-BTU/BHP-HR	1571011.0	1413910.0	14756.5	10861.1	10973.2	12073.9
BS DIESEL F. C. CORR.-LB/BHP-HR	86.4104	77.7693	0.8116	0.5974	0.6036	0.6641
BS SULFUR DIOXIDE-GR/BHP-HR	186.573	167.916	1.752	1.290	1.303	1.434
DRY AIR/FUEL RATIO-LB/LB	291.41	322.81	145.21	39.05	38.84	92.04
FUEL/DRY AIR RATIO-LB/LB	0.0034	0.0031	0.0069	0.0256	0.0257	0.0109
BS DRY AIR CONSUMPT.-LB/BHP-HR	24992.36	24916.76	116.98	23.16	23.26	60.67
CARBON DIOXIDE CALC.-PERC.-VOL.	0.72	0.65	1.44	5.46	5.49	2.28
OXYGEN CALC.-PERCENT-VOL.	19.90	19.99	18.92	13.49	13.45	17.78
BS HYDROCARBON DRY-GR/BHP-HR	4804.64	4540.86	15.77	0.0	0.0	3.83
BS NITROGEN OXIDE-GR/BHP-HR	0.0	0.0	0.0	17.20	18.22	18.65
BS NOX (HUM-CORREC.)GR/BHP-HR	0.0	0.0	0.0	17.19	18.58	19.02
BS CARBON MONOXIDE-GR/BHP-HR	3684.57	3773.28	11.65	2.89	1.94	4.32
BS PARTICULATE MATTER-GR/BHP-HR	0.0	0.0	0.0	0.0	0.0	0.0

VARIABLE INPUT DATA-		
LOG LINE - - - - - - - - - - - - -	14	16
ENGINE SPEED-RPM - - - - - - - - -	480.0	400.0
ENGINE LOAD-BHP - - - - - - - - - -	250.0	1.0
BAROMETER PRESSURE-INCH HG - -	30.10	30.10
DIESEL QUANTITY-LB - - - - - - - -	25.0	25.0
TIME-SEC. - - - - - - - - - - - - - -	514.3	1166.0
VAP. PRESS. H2O (SUCTTEMP)-PSIA	0.400	0.450
RELATIVE HUMIDITY-PERC.-ORI.T.	73.5	70.0
HYDROCARBONS-PPM-VOL. - - - - - -	613.	814.
METHANE-PPM-VOL. - - - - - - - -	0.	0.
OXIDES OF NITROGEN-PPM-VOL. - -	307.	62.
CARBON MONOXIDE-PPM-VOL. - - -	265.	335.
CARBON DIOXIDE-PPM-VOL. - - -	1.75	0.62
OXYGEN-PERCENT-VOL. - - - - - - -	17.96	19.17
PARTICULATE MATTER-GR/FT3 - - -	0.0	0.0
BOSCH SPOT NUMBER - - - - - - - - -	17.00	10.00
CALCULATED DATA-		
BMEP-PSI - - - - - - - - - - - - - -	19.89	0.10
BS DIESEL FUEL CONS.-BTU/BHP-HR	12822.2	1413910.0
BS DIESEL F. C. CORR.-LB/BHP-HR	0.7053	77.7693
BS SULFUR DIOXIDE-GR/BHP-HR - -	1.523	167.916
DRY AIR/FUEL RATIO-LB/LB - - -	116.77	322.81
FUEL/DRY AIR RATIO-LB/LB - - -	0.0086	0.0031
BS DRY AIR CONSUMPT.-LB/BHP-HR	81.74	24916.76
CARBON DIOXIDE CALC.-PERC.-VOL.	1.80	0.65
OXYGEN CALC.-PERCENT-VOL. - - -	18.44	19.99
BS HYDROCARBON DRY-GR/BHP-HR -	11.12	4490.23
BS NITROGEN OXIDE-GR/BHP-HR - -	18.08	1108.05
BS NOX (HUM-CORREC.)GR/BHP-HR	18.92	1186.97
BS CARBON MONOXIDE-GR/BHP-HR -	9.49	3674.59
BS PARTICULATE MATTER-GR/BHP-HR	0.0	0.0

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PROGRAM EGREM - VERSION 2/26/74

FIXED INPUT DATA-

ENGINE TYPE - - - - - - - - - -	-3888 1/8
SERIAL NUMBER - - - - - - - - -	-833681
NUMBER OF STROKE PER CYCLE - -	2
CYLINDER DISPLACEMENT-INCH3 - -	1037.0
NUMBER OF CYLINDER - - - - - -	10
LOG NUMBER - - - - - - - - - -	2
LOG DATE - - - - - - - - - - -	8/ 26/ 76
DIESEL FUEL SHOP NUMBER - - - -	2
DIESEL FUEL H.H.V.-BTU/LB - - -	19496.
DIESEL FUEL L.H.V.-BTU/LB - - -	18318.
DIESEL FUEL ATOMIC H/C RATIO -	1.77
DIESEL FUEL SULFUR-PCT-WEIGHT -	0.24
NO CORRECTION FACTOR -----	0.003360

VARIABLE INPUT DATA-

LOG LINE - - - - - - - - - - -	2	3	5	6	7	8	
ENGINE SPEED-RPM - - - - - - -	550.0	410.0	410.0	420.0	525.0	580.0	
ENGINE LOAD-[redacted] KW - - - - - -	23.0	1.0	26.0	242.0	447.0	690.0	— LOAD - KILOWATTS
BAROMETER PRESSURE-INCH HG - -	30.00	30.00	29.99	29.99	29.99	29.98	
DIESEL QUANTITY-LB - - - - - -	25.0	25.0	25.0	25.0	25.0	25.0	
TIME-SEC. - - - - - - - - - -	1240.5	1391.5	1211.6	550.6	320.4	224.5	
VAP. PRESS. H2O (SUCTTEMP)-PSIA	0.310	0.310	0.330	0.330	0.330	0.350	
RELATIVE HUMIDITY-PERC.-ORI.T.	90.0	90.0	89.0	89.0	89.0	88.0	
HYDROCARBONS-PPM-VOL. - - - - -	894.	992.	910.	474.	452.	398.	
METHANE-PPM-VOL. - - - - - - -	0.	0.	0.	0.	0.	0.	
OXIDES OF NITROGEN-PPM-VOL. - -	56.	51.	87.	415.	769.	983.	
CARBON MONOXIDE-PPM-VOL. - - -	322.	350.	338.	148.	115.	126.	
CARBON DIOXIDE-PPM-VOL. - - - -	0.85	0.60	0.85	2.35	3.35	4.40	
OXYGEN-PERCENT-VOL. - - - - - -	18.90	19.17	19.04	17.15	15.80	14.18	
PARTICULATE MATTER-GR/FT3 - - -	0.0	0.0	0.0	0.0	0.0	0.0	
[redacted] SMOKE %OPACITY	8.00	5.00	7.00	8.00	8.00	12.00	— SMOKE - % OPACITY

CALCULATED DATA-

BMEP-PSI ÷(1.341÷GEN. EFF.) - -	1.60	0.09	2.42	22.00	32.51	45.43	— BMEP ÷(1.341÷GEN. EFF.)
BS DIESEL FUEL CONS.-BTU/[redacted]-HR	57782.4	1184778.0	52334.5	12372.8	11511.2	10642.8	} /KW-HR
BS DIESEL F. C. CORR.-LB/[redacted]-HR	3.1782	65.1664	2.8786	0.6805	0.6332	0.5854	} /KW-HR
BS SULFUR DIOXIDE-GR/[redacted]-HR - -	6.862	140.704	6.215	1.469	1.367	1.264	} /KW-HR
DRY AIR/FUEL RATIO-LB/LB - - -	236.19	333.09	237.83	87.19	61.44	46.54	
FUEL/DRY AIR RATIO-LB/LB - - -	0.0042	0.0030	0.0042	0.0115	0.0163	0.0215	
BS DRY AIR CONSUMPT.-LB/[redacted]-HR	745.04	21543.79	679.49	58.89	38.61	27.04	— LB/KW-HR
CARBON DIOXIDE CALC.-PERC.-VOL.	0.88	0.63	0.88	2.41	3.44	4.56	
OXYGEN CALC.-PERCENT-VOL. - - -	19.67	20.02	19.68	17.61	16.22	14.70	
BS HYDROCARBON DRY-GR/[redacted]-HR -	147.22	4719.81	136.86	6.22	3.91	2.42	} GR/KW-HR
BS NITROGEN OXIDE-GR/[redacted]-HR - -	30.14	794.57	42.70	17.52	21.20	18.89	} GR/KW-HR
BS NOX (HUM-CORREC.)GR/[redacted]-HR -	31.08	819.44	44.74	18.36	22.21	20.11	} GR/KW-HR
BS CARBON MONOXIDE-GR/[redacted]-HR -	105.50	3319.78	101.00	3.81	1.93	1.47	} GR/KW-HR
BS PARTICULATE MATTER-GR/[redacted]-HR	0.0	0.0	0.0	0.0	0.0	0.0	} GR/KW-HR

VARIABLE INPUT DATA-

LOG LINE - - - - - - - - - - - - -	10	11	12	13
ENGINE SPEED-RPM - - - - - - - - -	650.0	410.0	410.0	410.0
ENGINE LOAD-BHP - - - - - - - - -	959.0	215.0	65.0	20.0
BAROMETER PRESSURE-INCH HG - -	29.98	29.97	29.97	29.96
DIESEL QUANTITY-LB - - - - - - -	25.0	25.0	25.0	25.0
TIME-SEC. - - - - - - - - - - - -	158.3	575.0	924.7	1260.0
VAP. PRESS. H2O (SUCTTEMP)-PSIA	0.350	0.380	0.380	0.380
RELATIVE HUMIDITY-PERC.-ORI.T.	88.0	87.0	87.0	87.0
HYDROCARBONS-PPM-VOL. - - - - - -	347.	485.	923.	974.
METHANE-PPM-VOL. - - - - - - - -	0.	0.	0.	0.
OXIDES OF NITROGEN-PPM-VOL. - -	1079.	348.	164.	83.
CARBON MONOXIDE-PPM-VOL. - - -	314.	247.	292.	292.
CARBON DIOXIDE-PPM-VOL. - - -	5.70	2.05	1.25	0.80
OXYGEN-PERCENT-VOL. - - - - - - -	12.42	17.15	18.09	18.63
PARTICULATE MATTER-GR/FT3 - - -	0.0	0.0	0.0	0.0
BOSCH SPOT NUMBER - - - - - - - -	25.00	6.00	3.00	3.00

CALCULATED DATA-

BMEP-PSI - - - - - - - - - - - - -	56.34	20.02	6.05	1.86
BS DIESEL FUEL CONS.-BTU/BHP-HR	10859.8	13335.6	27428.8	65421.4
BS DIESEL F. C. CORR.-LB/BHP-HR	0.5973	0.7335	1.5087	3.5984
BS SULFUR DIOXIDE-GR/BHP-HR - -	1.290	1.584	3.257	7.769
DRY AIR/FUEL RATIO-LB/LB - - -	36.13	97.85	158.75	246.68
FUEL/DRY AIR RATIO-LB/LB - - -	0.0277	0.0102	0.0063	0.0041
BS DRY AIR CONSUMPT.-LB/BHP-HR	21.42	71.23	237.71	881.02
CARBON DIOXIDE CALC.-PERC.-VOL.	5.91	2.15	1.32	0.85
OXYGEN CALC.-PERCENT-VOL. - - -	12.88	17.96	19.08	19.72
BS HYDROCARBON DRY-GR/BHP-HR -	1.68	7.71	48.78	190.22
BS NITROGEN OXIDE-GR/BHP-HR - -	16.33	17.81	28.07	52.51
BS NOX (HUM-CORREC.)GR/BHP-HR	17.38	19.45	30.65	57.34
BS CARBON MONOXIDE-GR/BHP-HR -	2.89	7.69	30.47	113.15
BS PARTICULATE MATTER-GR/BHP-HR	0.0	0.0	0.0	0.0

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PROGRAM EGREM - VERSION 2/26/74

FIXED INPUT DATA-

ENGINE TYPE	-38D8 1/8
SERIAL NUMBER	-833681
NUMBER OF STROKE PER CYCLE	2
CYLINDER DISPLACEMENT-INCH3	1037.0
NUMBER OF CYLINDER	10
LOG NUMBER	3
LOG DATE	9/ 1/ 76
DIESEL FUEL SHOP NUMBER	2
DIESEL FUEL H.H.V.-BTU/LB	19496.
DIESEL FUEL L.H.V.-BTU/LB	18318.
DIESEL FUEL ATOMIC H/C RATIO	1.77
DIESEL FUEL SULFUR-PCT-WEIGHT	0.24
NO CORRECTION FACTOR	0.003360

VARIABLE INPUT DATA-

LOG LINE	1	2	4	5	6	7
ENGINE SPEED-RPM	490.0	410.0	410.0	407.0	403.0	422.0
ENGINE LOAD-BHP	1.0	1.C	380.0	50.0	136.0	270.0
BAROMETER PRESSURE-INCH HG	30.03	30.03	30.04	30.04	30.05	30.05
DIESEL QUANTITY-LB	25.0	25.0	25.0	25.0	25.0	25.0
TIME-SEC.	1270.0	1600.0	391.4	1434.0	878.3	530.3
VAP. PRESS. H2O (SUCTTEMP)-PSIA	0.180	0.190	0.190	0.200	0.200	0.210
RELATIVE HUMIDITY-PERC.-ORI.T.	94.0	91.0	88.0	85.0	82.0	79.0
HYDROCARBONS-PPM-VOL.	177.	172.	96.	130.	119.	106.
METHANE-PPM-VOL.	0.	0.	0.	0.	0.	0.
OXIDES OF NITROGEN-PPM-VOL.	126.	117.	1253.	244.	447.	903.
CARBON MONOXIDE-PPM-VOL.	280.	290.	150.	216.	170.	127.
CARBON DIOXIDE-PPM-VOL.	0.95	0.80	3.40	1.00	1.70	2.65
OXYGEN-PERCENT-VOL.	19.71	19.84	15.93	18.50	17.42	16.20
PARTICULATE MATTER-GR/FT3	0.0	0.0	0.0	0.0	0.0	0.0
BOSCH SPOT NUMBER	5.00	4.00	6.00	4.00	4.00	4.00

CALCULATED DATA-

BMEP-PSI	0.08	0.09	35.39	4.69	12.89	24.43
BS DIESEL FUEL CONS.-BTU/BHP-HR	1298125.0	1030387.5	11084.5	22993.3	13801.9	11514.2
BS DIESEL F. C. CORR.-LB/BHP-HR	71.4008	56.6744	0.6097	1.2647	0.7591	0.6333
BS SULFUR DIOXIDE-GR/BHP-HR	154.165	122.369	1.316	2.731	1.639	1.367
DRY AIR/FUEL RATIO-LB/LB	221.35	261.77	61.13	198.93	116.61	75.38
FUEL/DRY AIR RATIO-LB/LB	0.0045	0.0038	0.0164	0.0050	0.0086	0.0133
BS DRY AIR CONSUMPT.-LB/BHP-HR	15686.05	14724.64	36.99	249.70	87.86	47.38
CARBON DIOXIDE CALC.-PERC.-VOL.	0.94	0.80	3.46	1.05	1.80	2.80
OXYGEN CALC.-PERCENT-VOL.	19.59	19.79	16.20	19.45	18.44	17.09
BS HYDROCARBON DRY-GR/BHP-HR	607.83	554.21	0.79	7.15	2.30	1.11
BS NITROGEN OXIDE-GR/BHP-HR	1421.62	1245.97	33.11	44.05	28.27	30.66
BS NOX (HUM-CORREC.)GR/BHP-HR	1313.60	1155.31	30.54	40.73	26.00	28.24
BS CARBON MONOXIDE-GR/BHP-HR	1930.97	1878.58	2.41	23.70	6.54	2.62
BS PARTICULATE MATTER-GR/BHP-HR	0.0	0.0	0.0	0.0	0.0	0.0

AD-A046 241 COLT INDUSTRIES BELOIT WI FAIRBANKS MORSE ENGINE DIV F/G 21/7
FIELD TESTS OF IN-SERVICE MODIFICATIONS TO IMPROVE PERFORMANCE --ETC(U)
AUG 77 E A KASEL, C L NEWTON, R A WALTER DOT-TSC-905

UNCLASSIFIED USCG-D-8-77 NL

2 OF 3
ADA
046241

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DATE
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CONT.

VARIABLE INPUT DATA-			
LOG LINE - - - - - - - - - - -	8	9	10
ENGINE SPEED-RPM - - - - - - - -	521.0	603.0	667.0
ENGINE LOAD-BHP - - - - - - - -	520.0	768.0	1030.0
BAROMETER PRESSURE-INCH HG - -	30.06	30.06	30.07
DIESEL QUANTITY-LB - - - - - -	25.0	25.0	25.0
TIME-SEC. - - - - - - - - - - -	296.7	209.8	153.0
VAP. PRESS. H2O (SUCTTEMP)-PSIA	0.210	0.220	0.220
RELATIVE HUMIDITY-PERC.-ORI.T.	75.0	72.0	69.0
HYDROCARBONS-PPM-VOL. - - - - -	91.	101.	129.
METHANE-PPM-VOL. - - - - - - -	0.	0.	0.
OXIDES OF NITROGEN-PPM-VOL. - -	1169.	1320.	1388.
CARBON MONOXIDE-PPM-VOL. - - -	108.	148.	296.
CARBON DIOXIDE-PPM-VOL. - - -	3.82	4.62	5.57
OXYGEN-PERCENT-VOL. - - - - - -	15.26	14.46	12.88
PARTICULATE MATTER-GR/FT3 - - -	0.0	0.0	0.0
BOSCH SPOT NUMBER - - - - - - -	10.00	17.00	18.00
CALCULATED DATA-			
BMEP-PSI - - - - - - - - - - -	38.11	48.64	58.97
BS DIESEL FUEL CONS.-BTU/BHP-HR	10685.6	10231.8	10461.4
BS DIESEL F. C. CORR.-LB/BHP-HR	0.5877	0.5628	0.5754
BS SULFUR DIOXIDE-GR/BHP-HR - -	1.269	1.215	1.242
DRY AIR/FUEL RATIO-LB/LB - - -	54.25	45.62	37.46
FUEL/DRY AIR RATIO-LB/LB - - -	0.0184	0.0219	0.0267
BS DRY AIR CONSUMPT.-LB/BHP-HR	31.64	25.48	21.40
CARBON DIOXIDE CALC.-PERC.-VOL.	3.90	4.66	5.70
OXYGEN CALC.-PERCENT-VOL. - - -	15.59	14.58	13.17
BS HYDROCARBON DRY-GR/BHP-HR -	0.64	0.57	0.62
BS NITROGEN OXIDE-GR/BHP-HR - -	26.37	23.90	21.00
BS NOX (HUM-CORREC.)GR/BHP-HR	24.10	21.86	19.09
BS CARBON MONOXIDE-GR/BHP-HR -	1.48	1.63	2.73
BS PARTICULATE MATTER-GR/BHP-HR	0.0	0.0	0.0

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PROGRAM EGREM - VERSION 2/26/74

FIXED INPUT DATA-

ENGINE TYPE - - - - - - - - - - -	3888 1/8
SERIAL NUMBER - - - - - - - - - -	833681
NUMBER OF STROKE PER CYCLE - -	2
CYLINDER DISPLACEMENT-INCH3 - -	1037.0
NUMBER OF CYLINDER - - - - - -	10
LOG NUMBER - - - - - - - - - -	4
LOG DATE - - - - - - - - - - -	9/ 2/ 76
DIESEL FUEL SHOP NUMBER - - - -	2
DIESEL FUEL H.H.V.-BTU/LB - - -	19496.
DIESEL FUEL L.H.V.-BTU/LB - - -	18318.
DIESEL FUEL ATOMIC H/C RATIO -	1.77
DIESEL FUEL SULFUR-PCT-WEIGHT -	0.24
NO CORRECTION FACTOR -----	0.003360

VARIABLE INPUT DATA-

LOG LINE - - - - - - - - - - - -	1	2	3	5	6	7
ENGINE SPEED-RPM - - - - - - - -	510.0	410.0	510.0	407.0	407.0	405.0
ENGINE LOAD-BHP - - - - - - - -	1.0	1.0	1.0	100.0	46.0	128.0
BAROMETER PRESSURE-INCH HG - -	30.20	30.20	30.20	30.20	30.20	30.20
DIESEL QUANTITY-LB - - - - - - -	25.0	25.0	25.0	25.0	25.0	25.0
TIME-SEC. - - - - - - - - - - -	1220.0	1600.0	1220.0	1125.0	1434.0	925.0
VAP. PRESS. H2O (SUCTTEMP)-PSIA	0.135	0.140	0.150	0.160	0.170	0.180
RELATIVE HUMIDITY-PERC.-ORI.T.	92.0	90.0	87.0	85.0	82.0	80.0
HYDROCARBONS-PPM-VOL. - - - - -	156.	160.	164.	158.	152.	157.
METHANE-PPM-VOL. - - - - - - -	0.	0.	0.	0.	0.	0.
OXIDES OF NITROGEN-PPM-VOL. - -	123.	110.	112.	294.	206.	388.
CARBON MONOXIDE-PPM-VOL. - - -	304.	325.	312.	232.	264.	188.
CARBON DIOXIDE-PPM-VOL. - - -	0.90	0.80	0.91	1.35	1.02	1.55
OXYGEN-PERCENT-VOL. - - - - - -	19.73	19.83	19.73	19.19	19.89	19.06
PARTICULATE MATTER-GR/FT3 - - -	0.0	0.0	0.0	0.0	0.0	0.0
BOSCH SPOT NUMBER - - - - - - - -	4.00	3.00	3.00	2.00	2.00	7.00

CALCULATED DATA-

BMEP-PSI - - - - - - - - - - - -	0.07	0.09	0.07	9.38	4.32	12.07
BS DIESEL FUEL CONS.-BTU/BHP-HR	1351327.0	1030387.5	1351327.0	14654.4	24992.7	13924.2
BS DIESEL F. C. CORR.-LB/BHP-HR	74.3271	56.6744	74.3271	0.8060	1.3747	0.7659
BS SULFUR DIOXIDE-GR/BHP-HR - -	160.484	122.369	160.484	1.740	2.968	1.654
DRY AIR/FUEL RATIO-LB/LB - - -	233.07	261.65	230.66	156.19	208.91	137.06
FUEL/DRY AIR RATIO-LB/LB - - -	0.0043	0.0038	0.0043	0.0064	0.0048	0.0073
BS DRY AIR CONSUMPT.-LB/BHP-HR	17193.45	14717.64	17016.17	124.95	285.03	104.18
CARBON DIOXIDE CALC.-PERC.-VOL.	0.90	0.80	0.91	1.34	1.00	1.53
OXYGEN CALC.-PERCENT-VOL. - - -	19.65	19.79	19.64	19.06	19.51	18.80
BS HYDROCARBON DRY-GR/BHP-HR -	585.45	516.11	610.58	4.32	9.51	3.60
BS NITROGEN OXIDE-GR/BHP-HR - -	1526.21	1171.95	1371.54	26.48	42.31	29.08
BS NOX (HUM-CORREC.)GR/BHP-HR	1352.46	1040.20	1222.25	23.71	38.00	26.23
BS CARBON MONOXIDE-GR/BHP-HR -	2298.35	2104.22	2334.42	12.72	33.07	8.59
BS PARTICULATE MATTER-GR/BHP-HR	0.0	0.0	0.0	0.0	0.0	0.0

VARIABLE INPUT DATA-				
LOG LINE - - - - - - - - - - - -	8	9	10	11
ENGINE SPEED-RPM - - - - - - - -	415.0	529.0	540.0	641.0
ENGINE LOAD-BHP - - - - - - - -	160.0	490.0	435.0	897.0
BAROMETER PRESSURE-INCH HG - -	30.20	30.20	30.20	30.20
DIESEL QUANTITY-LB - - - - - -	25.0	25.0	25.0	25.0
TIME-SEC. - - - - - - - - - - -	802.0	316.0	345.0	179.0
VAP. PRESS. H2O (SUCTTEMP)-PSIA	0.200	0.210	0.220	0.240
RELATIVE HUMIDITY-PERC.-ORI.T.	77.0	75.0	72.0	68.0
HYDROCARBONS-PPM-VOL. - - - - -	159.	77.	74.	146.
METHANE-PPM-VOL. - - - - - - -	0.	0.	0.	0.
OXIDES OF NITROGEN-PPM-VOL. - -	534.	1022.	938.	1273.
CARBON MONOXIDE-PPM-VOL. - - -	157.	99.	107.	282.
CARBON DIOXIDE-PPM-VOL. - - -	1.98	3.50	3.38	5.00
OXYGEN-PERCENT-VOL. - - - - - -	18.41	16.30	16.87	13.51
PARTICULATE MATTER-GR/FT3 - - -	0.0	0.0	0.0	0.0
BOSCH SPOT NUMBER - - - - - - - -	8.00	9.00	7.00	15.00
CALCULATED DATA-				
BMEP-PSI - - - - - - - - - - - -	14.72	35.37	30.76	53.44
BS DIESEL FUEL CONS.-BTU/BHP-HR	12847.7	10647.2	10985.2	10267.7
BS DIESEL F. C. CORR.-LB/BHP-HR	0.7067	0.5856	0.6042	0.5648
BS SULFUR DIOXIDE-GR/BHP-HR - -	1.526	1.264	1.305	1.219
DRY AIR/FUEL RATIO-LB/LB - - -	107.14	60.85	64.18	41.35
FUEL/DRY AIR RATIO-LB/LB - - -	0.0093	0.0164	0.0156	0.0242
BS DRY AIR CONSUMPT.-LB/BHP-HR	75.15	35.37	38.49	23.18
CARBON DIOXIDE CALC.-PERC.-VOL.	1.96	3.47	3.29	5.15
OXYGEN CALC.-PERCENT-VOL. - - -	18.22	16.17	16.42	13.91
BS HYDROCARBON DRY-GR/BHP-HR -	2.63	0.60	0.63	0.75
BS NITROGEN OXIDE-GR/BHP-HR - -	28.82	25.81	25.81	20.92
BS NOX (HUM-CORREC.)GR/BHP-HR	26.24	23.57	23.59	19.20
BS CARBON MONOXIDE-GR/BHP-HR -	5.16	1.52	1.79	2.82
BS PARTICULATE MATTER-GR/BHP-HR	0.0	0.0	0.0	0.0

APPENDIX G

REPORT OF INVENTIONS

The work performed under this contract produced no new inventions; however, methods are described, using modifications of existing technology, that will reduce emissions and improve the fuel economy of Coast Guard icebreaker diesel engines and other similar engines in the Coast Guard fleet. The modifications described on page 12 would also be applicable to other FM 3808 1/8 engines used as stationary or mobile sources.

125 copies

AD-A046 241   COLT INDUSTRIES BELOIT WI FAIRBANKS MORSE ENGINE DIV   F/G 21/7

FIELD TESTS OF IN-SERVICE MODIFICATIONS TO IMPROVE PERFORMANCE --ETC(U)

AUG 77   E A KASEL, C L NEWTON, R A WALTER   DOT-TSC-905

UNCLASSIFIED   USCG-D-8-77   NL

3 OF 3

AD A046241

SUPPLEMENTARY

INFORMATION

END

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7-78

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INFORMATION

AD-A046241

DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD

MAILING ADDRESS
U.S. COAST GUARD G-DSA-3/TP44
WASHINGTON, D.C. 20590
PHONE: 202-426-1050

3918
Ser: 097
MAR 20 1978

From: Commandant
To : Mr. J.E. Cundiff, Defense Documentation Center/TCA,
Cameron Station, Alexandria, Va. 22314

Subj: Proprietary Information

Ref : (a) U.S. Coast Guard letter dated 24 Jan 1978, file 3918, Serial 084 to Chief, Accessions Division, Defense Logistics Agency DDC.
(b) Your phone conversation with LT T.J. Marhevko, USCG, On 8 Mar 1978.

1. A draft and smooth copy of the final report entitled "Field Tests of In-Service Modifications to Improve Performance of an Icebreaker Main Diesel Engine" (CG-D-8-77) was sent to you as the enclosures to reference (a).

2. In reference (b) you questioned the use of information on page 48 of the above named study due to its proprietary nature. Please be advised that this information is not considered proprietary to our contractor, Colt Industries, as explained in enclosure (1).

3. I understand that the accession number of this report will remain AD-A046 241/6WO.

W. M. VEILLETTE
By direction

Enclosures: (1) Copy of Colt Industries letter dated 16 March 1978 to Commandant (G-DSA-3) U.S. Coast Guard

Colt Industries

Fairbanks Morse
Engine Division
701 Lawton Avenue
Beloit, Wisconsin 53511
608/364-4411

ENCLOSURE(/)

March 16, 1978

Commodat
Coast Guard Headquarters
Trans Point Building
2100 Second Southwest
Room 4402
Washington, D.C. 20590

COPY

Attention: G-DSA3
Lt. Comdr. Tom Marhevko

Subject: DOT-TSC-905
F.M. #938642

Enclosure: (1) Colt Industries Drawing No. 16 204 296 - Exhaust Stack Extension Assembly

Gentlemen:

The attached drawing is forwarded for your use and is not considered proprietary to Colt Industries; therefore, we have removed the statement from enclosure (1).

This is in response to your telephone request to Mr. Gene Kasel.

Yours very truly,

COLT INDUSTRIES OPERATING CORP
FAIRBANKS MORSE ENGINE DIVISION

W. A. Schlagenhaft
W. A. Schlagenhaft
Supervisor, Contract Administration

WAS:lmh

cc: G. Kasel