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U.S. COAST GUARD POLLUTION ABATEMENT PROGRAM - TWO-STROKE CYCLE OUTBOARD ENGINE EMISSIONS

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FINAL REPORT

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16. Abstract

This report documents the results of emissions tests performed on three old and two new outboard engines. Tests of the emissions were made before and after water contact. Older engines were tested in as-received condition, tuned to factory specifications and retested. After being tuned, these engines showed improvements in emissions and fuel consumption. The new engines with improved ignition and combustion chamber design and crankcase drainage recycling showed less emission and better fuel consumption characteristics than the older engines. The results of these tests were used to calculate the emissions impact of the United States Coast Guard outboard fleet for comparison with the emissions impact of other Coast Guard vessels and vessels in general.

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PREFACE

The U.S. Coast Guard is engaged in a continuing effort to minimize exhaust emissions from Coast Guard power plants. This effort includes investigation of the following related factors:

1. Extent of exhaust emissions to the air from two-stroke outboard engines as a function of age and operating condition.
2. Determination of the effect of tune-up on exhaust emission and fuel consumption of older engines.
3. Effect of water/exhaust mixing on exhaust emissions to the air.

This report, sponsored by the U.S. Coast Guard, Office of Research and Development, describes and analyzes the work performed and the results obtained during this investigation by the U.S. Department of Transportation, Transportation Systems Center (TSC).

The author is pleased to acknowledge the valuable cooperation provided through the duration of the project by Cdr. Robert J. Ketchel, Lt. Roswell W. Ard, and Lt. Cdr. James R. Sherrard, Coast Guard Project Officers for 1972-1973, 1974, and 1975 respectively. In addition, grateful acknowlegement is given for the significant contributions provided by Earl C. Klaubert, Richard A. Roberts, and Charles R. Hoppen of TSC.

The author would also like to thank James Kelley, Raytheon Service Company, for his help in preparing and organizing this report.

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1. INTRODUCTION

This report describes the results of exhaust emission tests performed on two-stroke cycle outboard engines at the Marine Engine Test Facility located at the Army Materials and Mechanics Research Center (AMMRC), Watertown, Massachusetts. These tests provided for analysis of new engines and older engines of the type commonly used on privately-owned craft. The existing literature on outboard engine testing has been almost totally directed toward testing of new engines (see References 1 and 2). Little data has been available on emissions from older engines which are still present in significant numbers. The test results described in this report detail the potential for emission improvement of older engines resulting from engine tune-up. Also, because outboard engines exhaust below water level, additional engine tests were included to determine the relative distribution of exhaust products above and below the water.

Although the results reported apply to a relatively limited statistical sampling, the data obtained will serve as a data base for the Coast Guard and other interested agencies.

2. TEST PREPARATION AND PROCEDURE

2.1 TEST ENGINES

The test program involved analysis of five outboard engines, whose nominal characteristics are indicated in Table 1.

TABLE 1. OUTBOARD ENGINES TESTED

MAKE	YEAR	RATED HP
Johnson	1959	50
Mercury	1964	65
Mercury	1962	70
Evinrude	1974	40
Mercury	1972	40

Three of these engines were older models, ranging in age from 10 to 15 years. Although total engine hours of use and total operating hours since the last tune-up were not known, the engines functioned adequately during performance tests. Information made available by the former owners of these engines indicated that, except for winterizing, maintenance procedures, such as engine tune-up, were rarely performed, and that starting readily and continuous operation were the sole criteria for satisfactory engine performance. Operation under the conditions described is common for many privately-owned outboard engines; thus, although the present sampling is limited in quantity, the assumption that these maintenance conditions are typical for older engines is considered valid in this discussion.

The exhaust emission tests on these older models provided test data for two conditions as a basis for comparison: first, for the original existing condition of the engines at the time of their procurement; and secondly, for their performance after a tune-up in accordance with factory specifications.

Two new engines were also tested (after break-in) to compare these results with the results obtained from older engines in the untuned and tuned condition.

2.2 TEST CYCLES

The load horsepower applied to the engines tested in this program followed the generally accepted power curve for planing hull boats:

$$P = K(S)^{2.5}$$

where

P = horsepower

K = a constant

S = engine speed (rpm).

The factor K, which was calculated for each engine at its rated speed and horsepower, was then used to calculate the load to be applied at the engine speeds of interest (usually increments of 1000 rpm). Table 2 gives the conditions of speed and load for each engine tested. These loads and crankshaft rpm were continuously monitored throughout the test runs.

TABLE 2. APPLIED HP FOR TEST ENGINES

SPEED RPM	1959 Johnson	1965 Mercury	1962 Mercury	1974 Evinrude	1972 Mercury
700-800	-	-	-	-	-
1000	1.16	1.05	0.937	0.93	0.715
2000	6.58	5.96	5.58	5.27	4.05
3000	18.14	16.43	15.38	14.51	11.15
4000	37.25	33.73	31.57	29.80	22.89
4500	50.00	-	-	40.00	-
5000		58.93	55.16		40.00
5200		65.00	-		
5500			70.00		

2.3 TEST CELL

The engines were tested in the specially constructed Engine Exhaust Emissions Test Cell (Figure 1) located in Watertown, Massachusetts. It is operated by the Transportation Systems Center under the auspices of the USCG to test USCG diesels and outboard engines. The cell was designed to attenuate engine noise and satisfy the safety requirements associated with operating gasoline-fueled engines. The cell and its associated instrumentation was described in a previous report (Reference 3). However, those aspects of the cell and its associated equipment considered important for the understanding of this study will be described briefly herein.

2.3.1 Engine Test Mount

The outboard engines (OE's) under test were rigidly attached to a universal support structure or test mount weighing nearly 1000 pounds (Figure 2). This mount provides precise positioning of OE's with short (15") or long (20") shaft engines so that their propeller shafts are precisely in axial alignment with the dynamometer drive shaft.

The test mount also contains the lower unit enclosure, fuel system, and electric start panel. The lower unit enclosure (Figure 3) contains the water tank which is equipped with adjustable jack screws for engine alignment. The two-piece tank cover is attached to the exhaust duct and serves to confine the water splashed up by the drive shaft and engine exhaust. Figure 4 is a view of the lower unit tank including the lower unit restraint plate. Each restraint plate is specially molded to fit the lower unit of the particular engine under test. Also seen in Figure 4 is part of the recirculation system which pumps tank water past the OE's lower unit for cooling and to simulate an engine's normal motion through the water.

2.3.2 Engine Cooling

Figure 5 shows the outboard engine cooling and water circulation layout. The tank water is constantly resupplied by

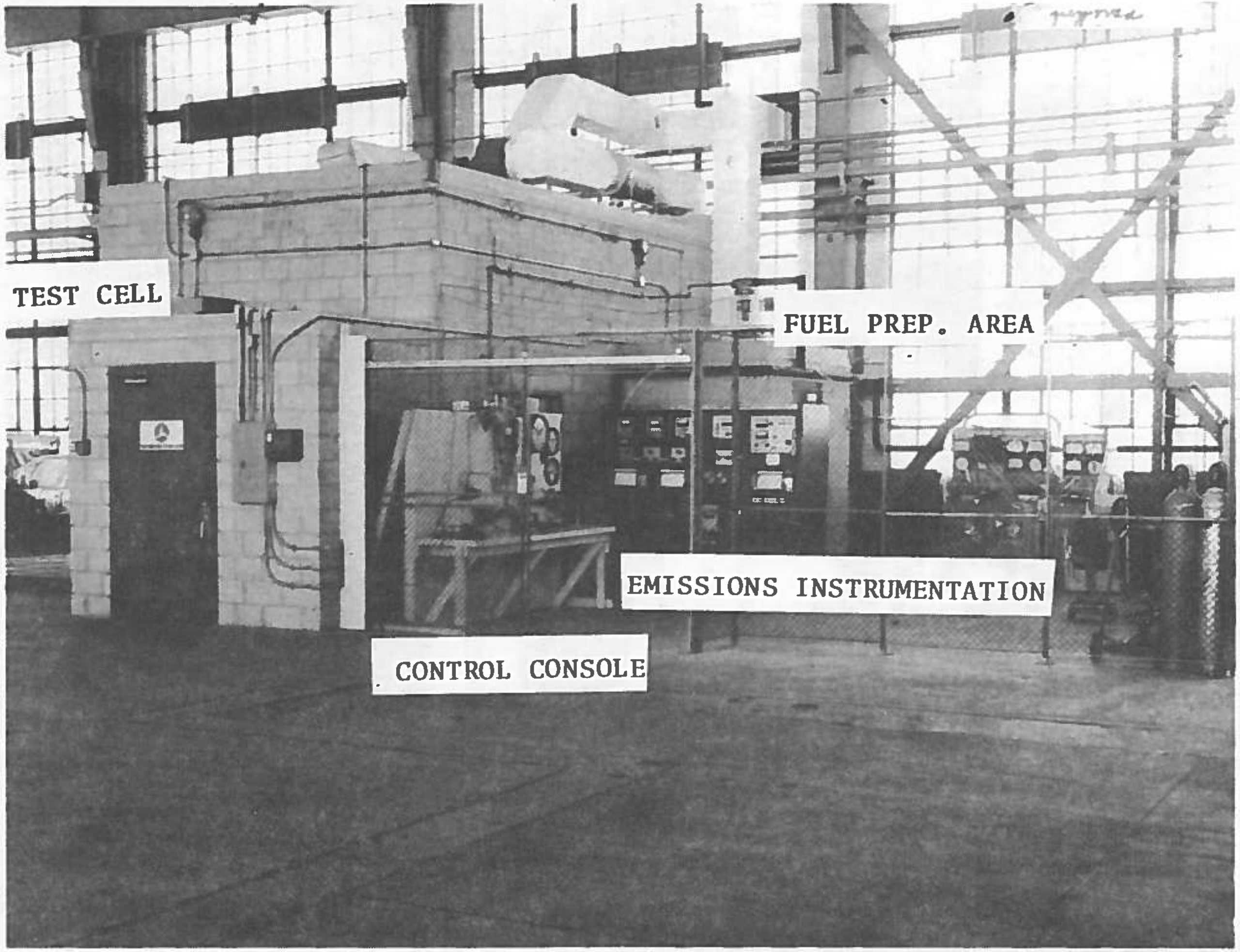


Figure 1. Exterior View of Test Cell and Ancillary Equipment

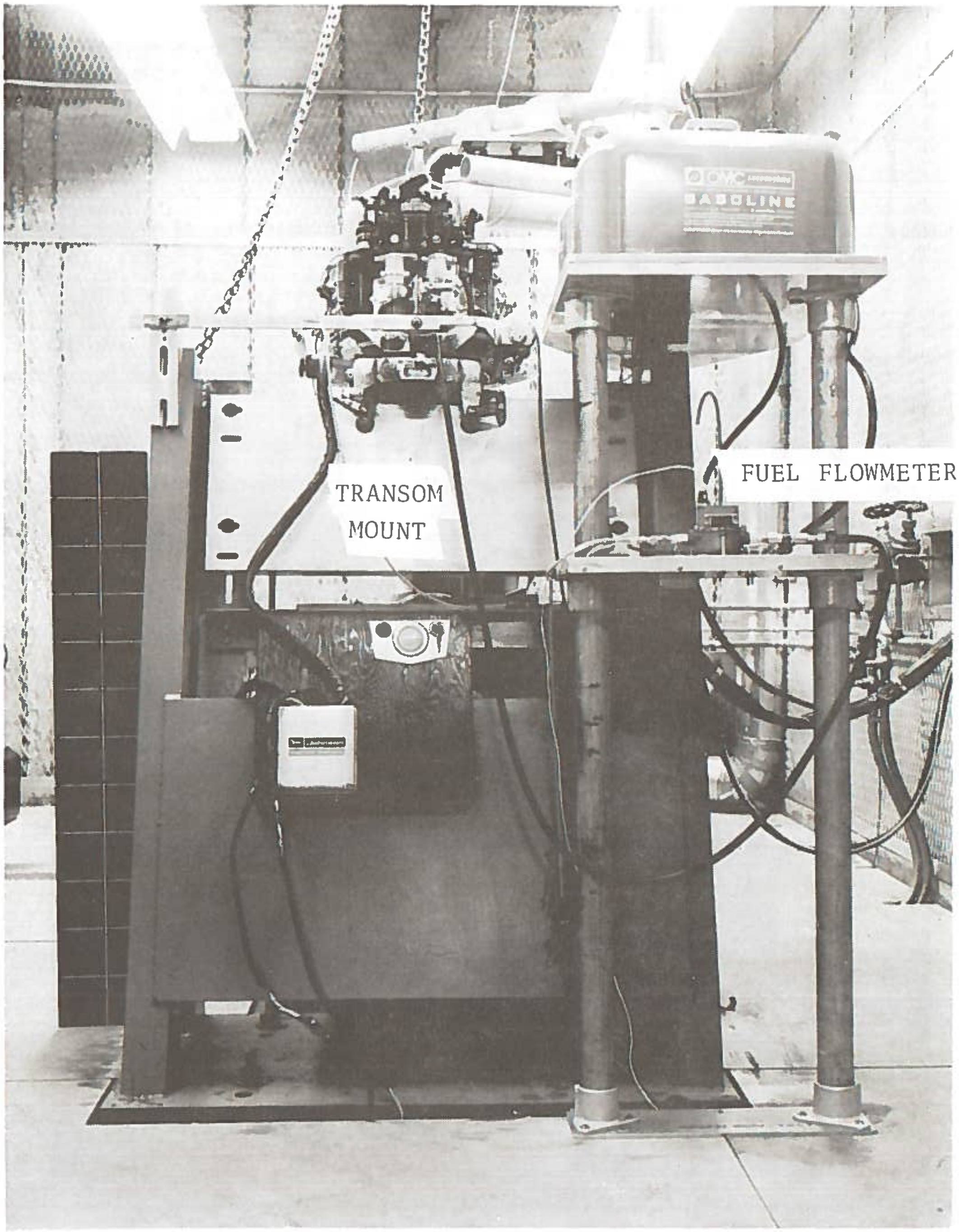


Figure 2. Outboard Engine Test Stand

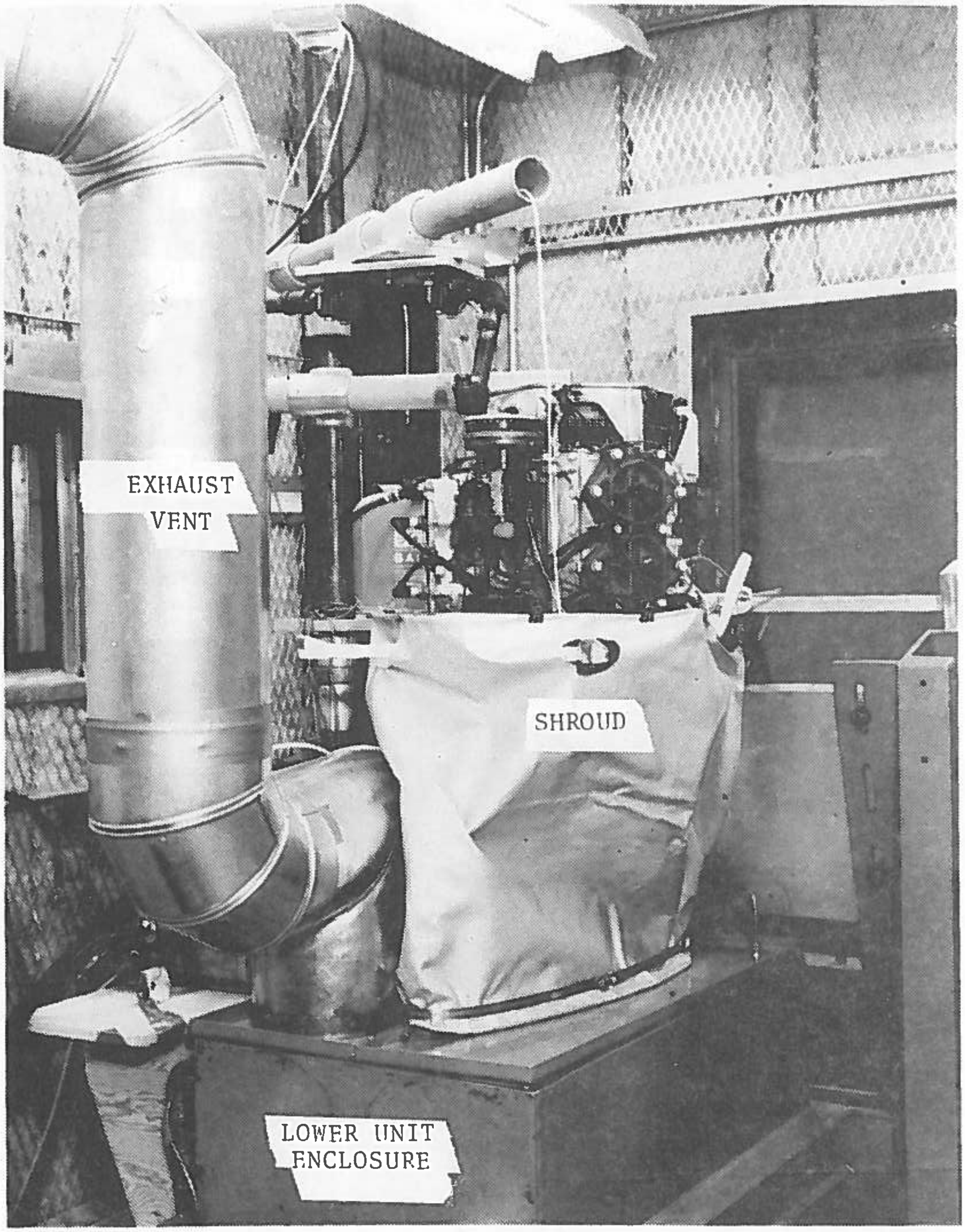


Figure 3. Outboard Engine and Lower Unit Enclosure

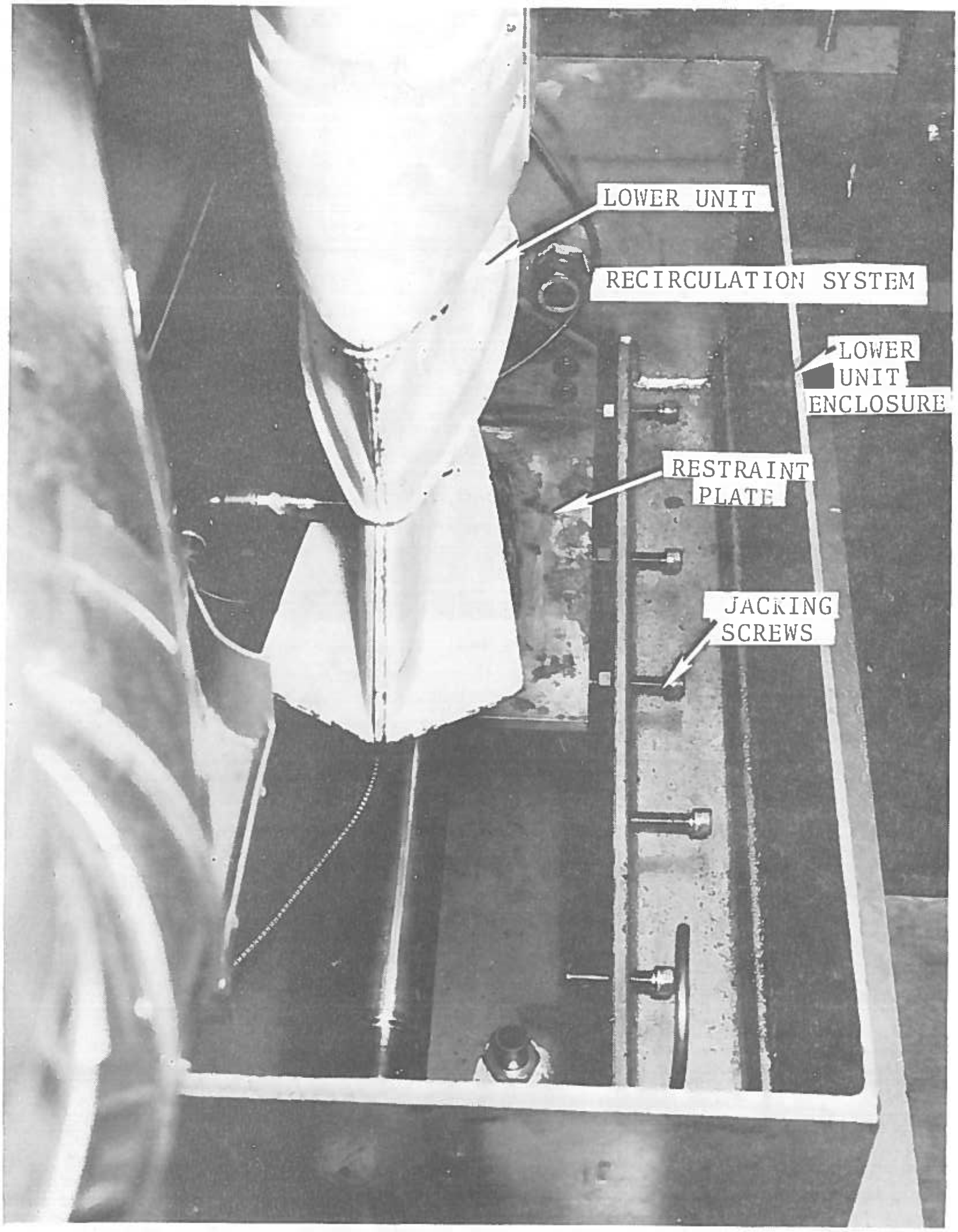


Figure 4. View of Lower Unit Tank

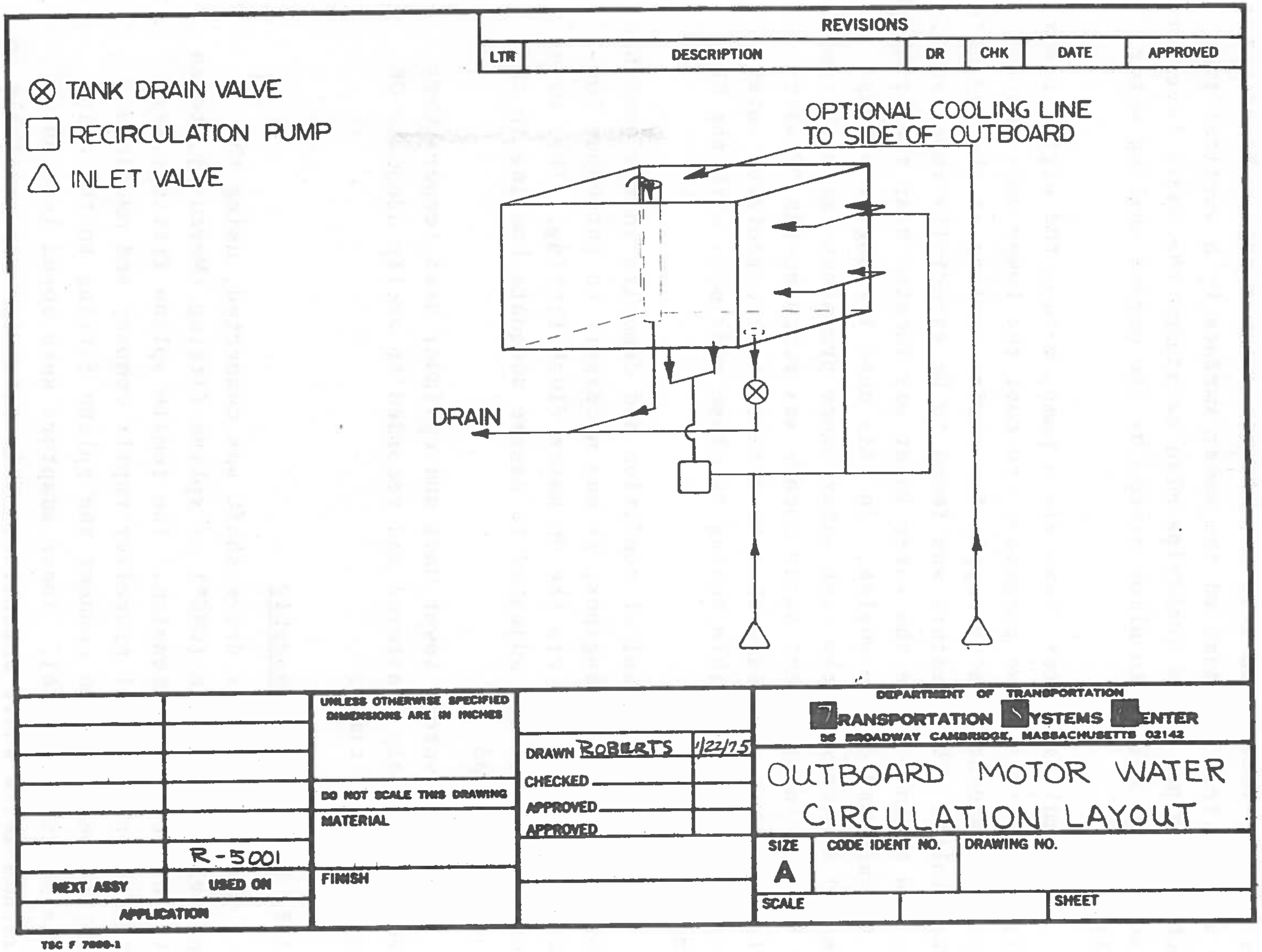


Figure 5. Outboard Engine Water Circulation Layout

fresh water introduced into the recirculation system. Waste water is drained from the tank at the water surface by a vertical two-inch standpipe. This standpipe also maintains the water level at a sufficient height to allow pickup by the engine cooling water inlet.

Recirculated water flows via a pump, around the engine lower unit. This serves two purposes: to cool the lower unit and to assure an adequate water supply for engine cooling at the engine's water inlet. This feature was found to be especially important for the new engines where the water inlet was located near the trim-tab at the aft end of the engine. In this case the engine exhaust created a vortex in the tank water (more prevalent at high rpm) so that an insufficient water supply was reaching the OE water inlet. It was necessary then to extend the recirculated water-supply inlet by flexible tubing to close proximity with the OE water inlet.

Because of mechanical condition and deposits in the cooling system of the older engines, it was necessary to introduce low-pressure fresh water via the OE water-flush fitting. This water flow could be easily adjusted to assure adequate cooling to the OE cylinder head.

The tank water, lower unit and cylinder head temperatures were continuously monitored and recorded to verify adequate OE cooling at all times.

2.3.3 Drive Shaft Assembly

The OE propeller drive shaft was connected, using the appropriate shear-pin (OMC*) or spline fitting (Mercury), to an axial-drive shaft extension. The female spline fittings were obtained from a local propeller repair company and machined adaptors were used to connect the spline fitting to the axial drive shaft (Figure 6). These adaptors were keyed into an aluminum drive shaft extension. This extension was available in

*Outboard Marine Corp.

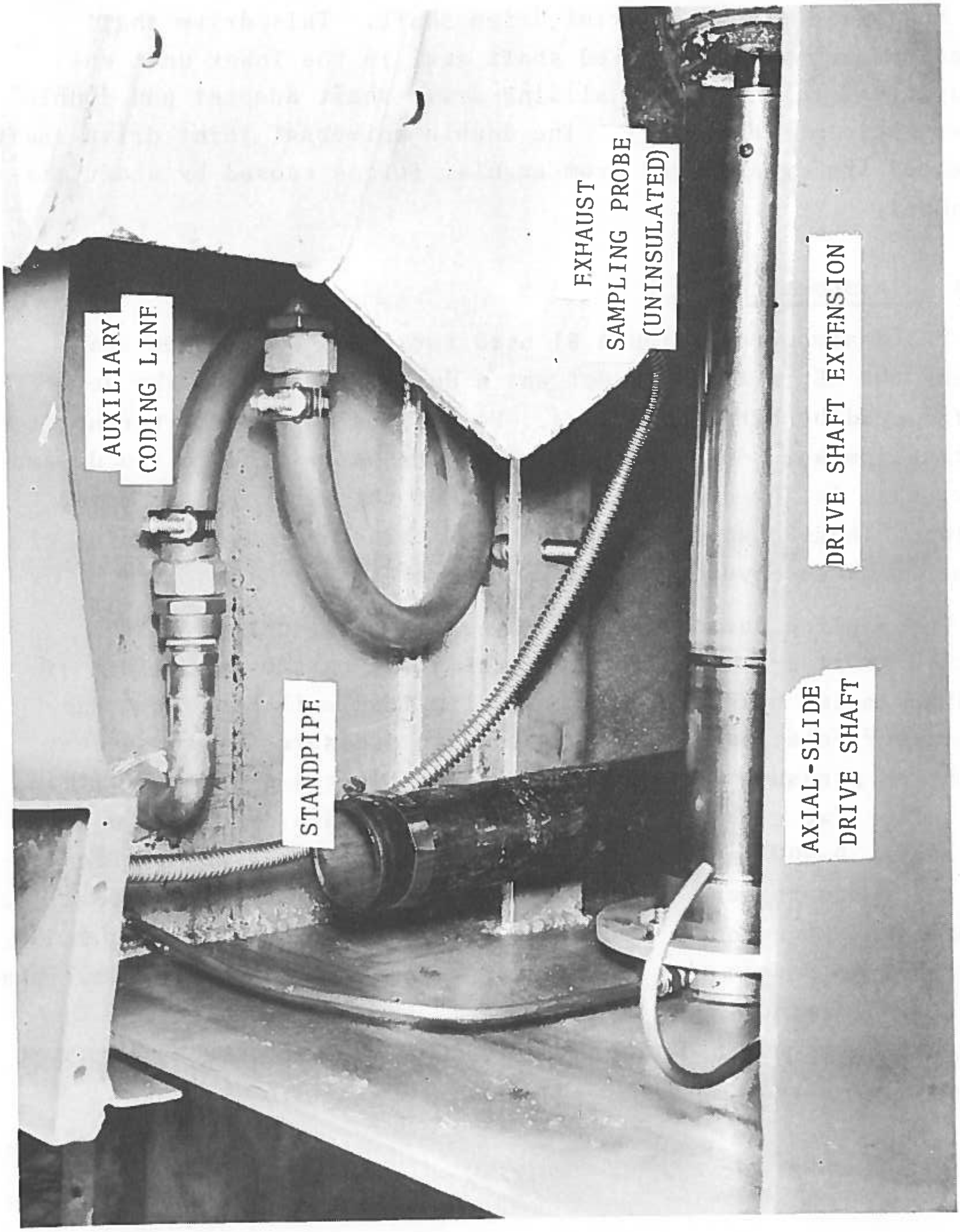


Figure 6. View of Lower Unit Tank and Drive Shaft

three lengths to accommodate the different sizes of lower units encountered in this study. The extensions were fitted and keyed into the stainless steel axial drive shaft. This drive shaft passed through a water-cooled shaft seal in the lower unit enclosure tank to an axially sliding drive shaft adapter and double universal joint (Figure 7). The double universal joint drive shaft protected the dynamometer from angular forces caused by shaft misalignment.

2.3.4 Dynamometer

The dynamometer (Figure 8) used for power absorption when testing the OE in this project was a dual-rotor waterbrake device manufactured by Kahn Industries. Variations in applied torque at constant rpm were obtained by varying the water flow to the dynamometer; that is, by changing the depth of the water in the rotor housing. These changes are possible within the control limits of the performance envelope given in Figure 9.

The applied torque was sensed by a hydraulic load cell attached at floor level to a vertical strut on the torque arm of the dynamometer housing. The hydraulic load cell converted the dynamometer rotational braking torque to pressure for subsequent readout on pressure (Bourdon) type gages located external to the test cell. Two gages were available to indicate dyno torque in two ranges, 0-900 in-lbs. and 0-9000 in-lbs. The hydraulic load cell and readouts were calibrated at least daily during OE testing. Calibration was accomplished by hanging the appropriate weights on a vertical holder on the dynamometer torque arm. A typical calibration curve for the 0-900 in-lb. gage is shown in Figure 10. The torque readings taken during a test run were corrected by means of calibration curves.

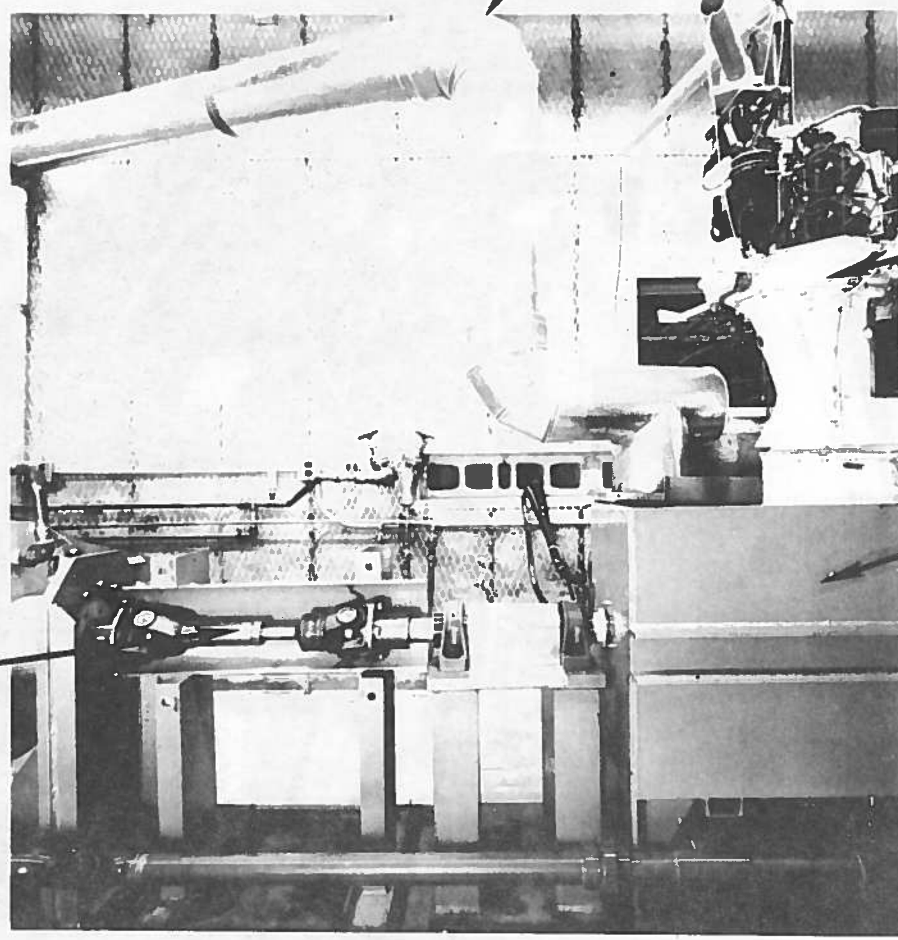


Figure 7. Side View of Drive Train

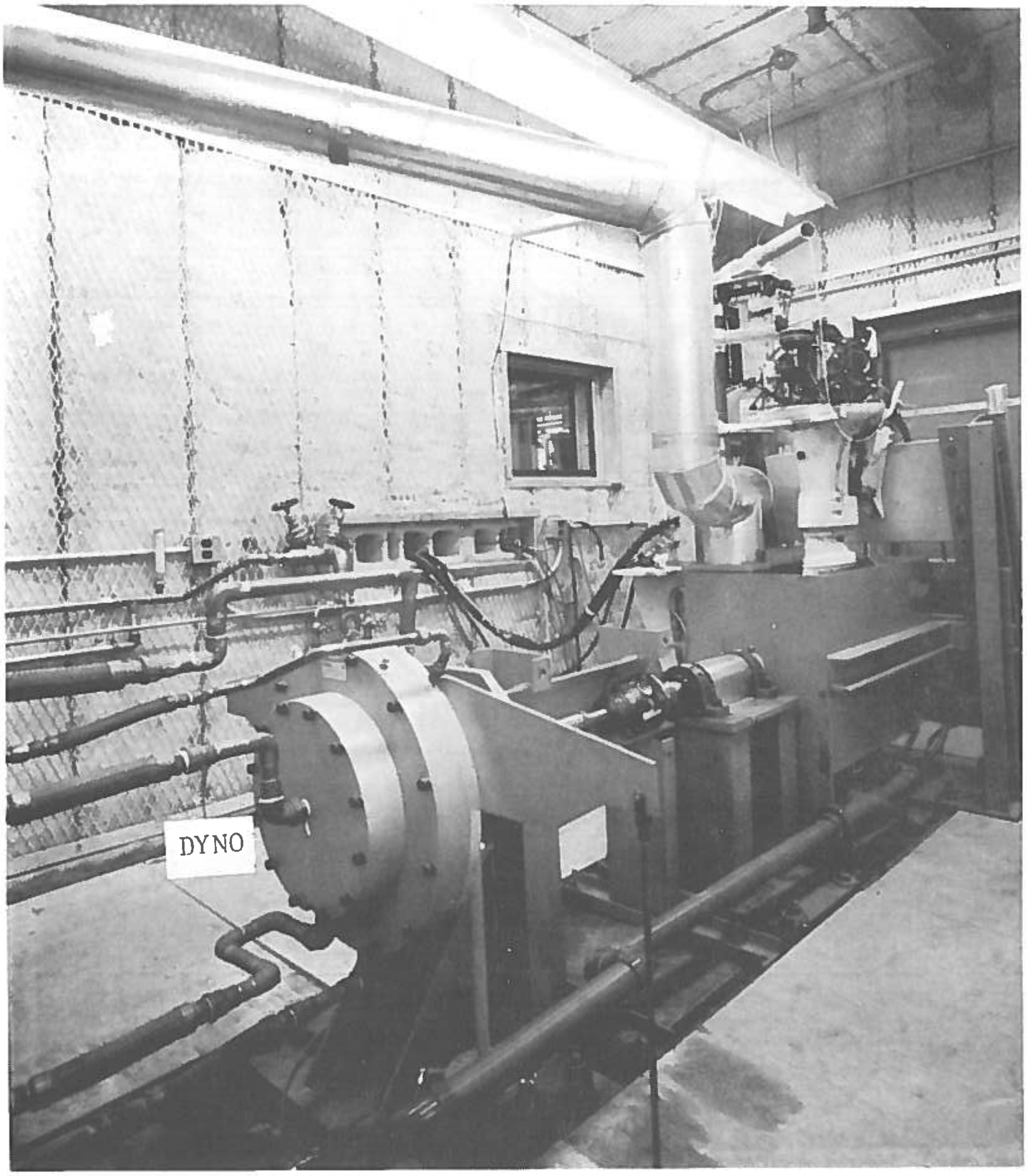


Figure 8. Water Brake Dynamometer, Test Cell Interior

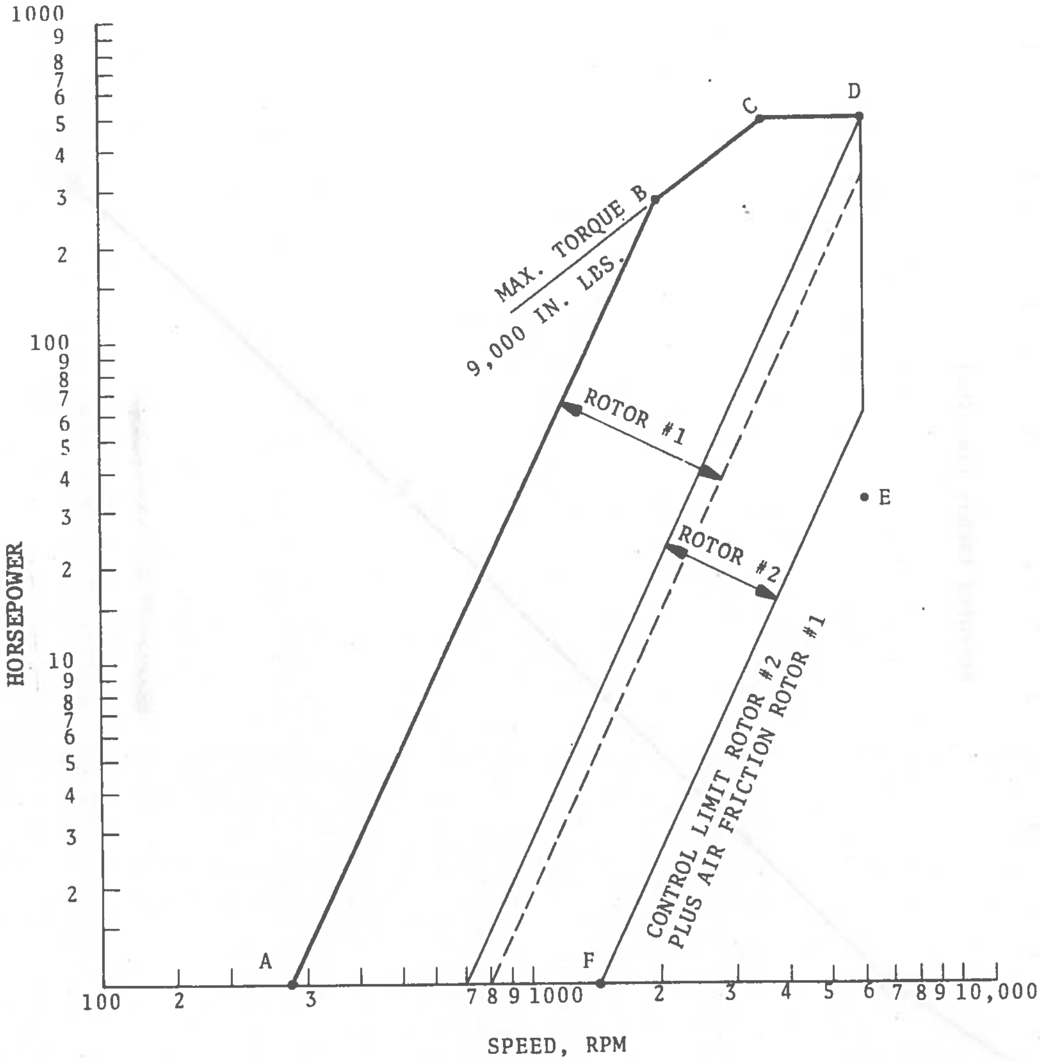


Figure 9. Performance Envelope of Dual-Rotor Dynamometer

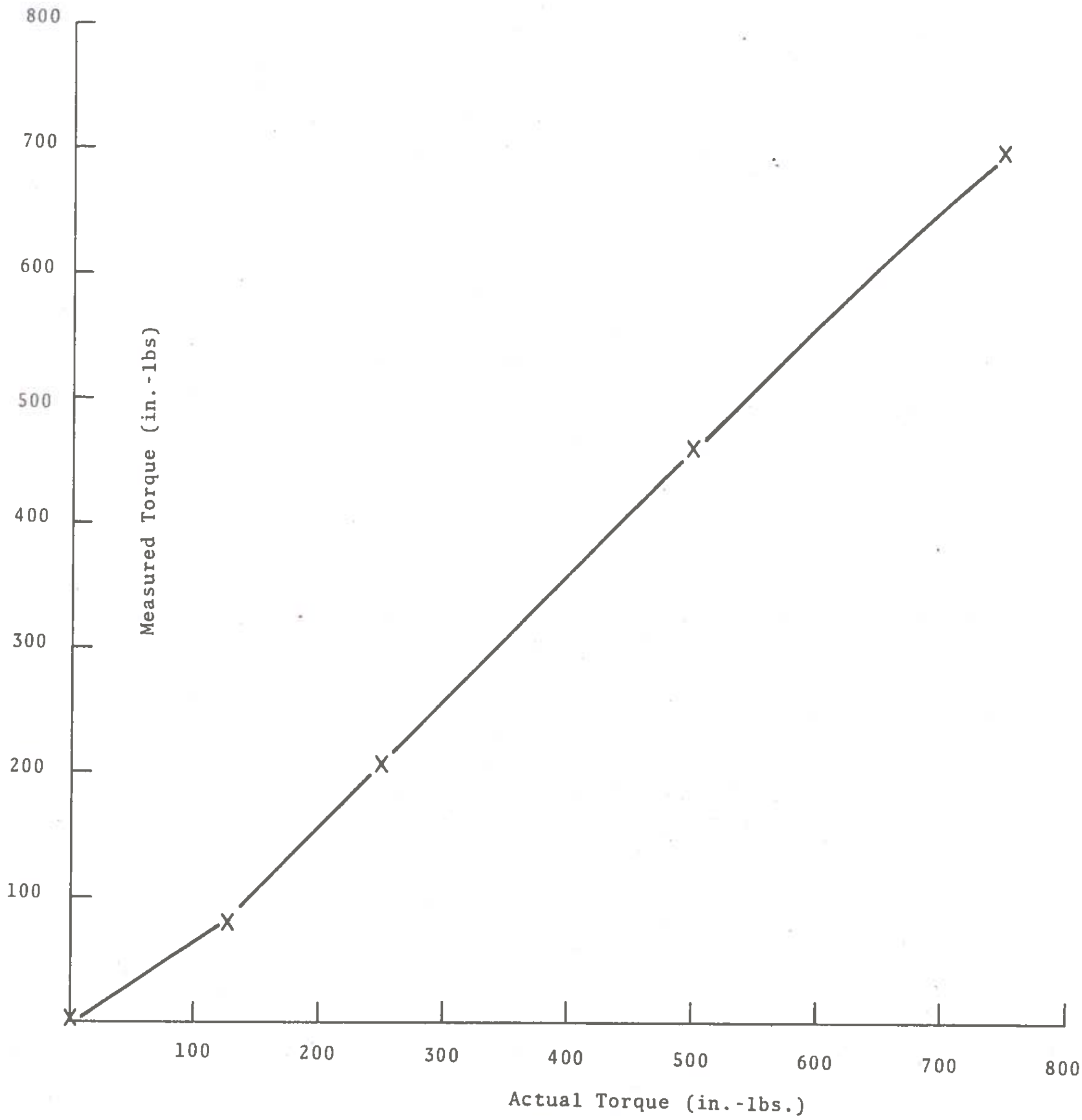


Figure 10. Typical Torque Meter Calibration Curve

2.4 ANCILLARY EQUIPMENT

Other ancillary equipment to monitor the operating parameters of the engine and its working environment will be briefly described.

2.4.1 Crankshaft and Propeller Shaft Speed

A universal crankshaft rpm monitor (tachometer) was developed for this program. This universal tachometer was used to monitor the speed of each engine tested in this program. A chopper disc of alternately reflective and non-reflective segments was mounted on the flywheel (or auxiliary accessory at the same rpm) of the test OE (Figure 11). An opto-electronic sensing head composed of an infrared emitting diode (IRED) and a photo transistor generated and detected the light signal. As the flywheel rotated, alternate reflective and non-reflective segments of the disc were seen by the light source and its detector, thus producing a pulsed output which was made compatible with a standard magnetic sensing tachometer readout. This tachometer has an adjustable overspeed and under-speed ignition cut-off to assure engine operation only within the speed capabilities of the test OE. A momentary switch was provided to bypass the low speed cut-off when starting the engine.

The propeller shaft rpm was continuously monitored by a magnetic-type tachometer that was supplied as part of the dynamometer.

Both tachometers were periodically calibrated against two stroboscopes at speeds varying from idle (600-800 rpm) to high speed (5000 rpm). The tachometer readings never varied by more than ±5% from the stroboscope readings and generally were within ±2%. The propeller-shaft tachometer had a tendency to "zero drift" and it was necessary to reset the zero at least daily.

2.4.2 Fuel Consumption

Fuel flow to the engine was continuously measured using a positive displacement-type fuel flow meter (Figure 12). The fuel was supplied from one of two standard six-gallon fuel tanks

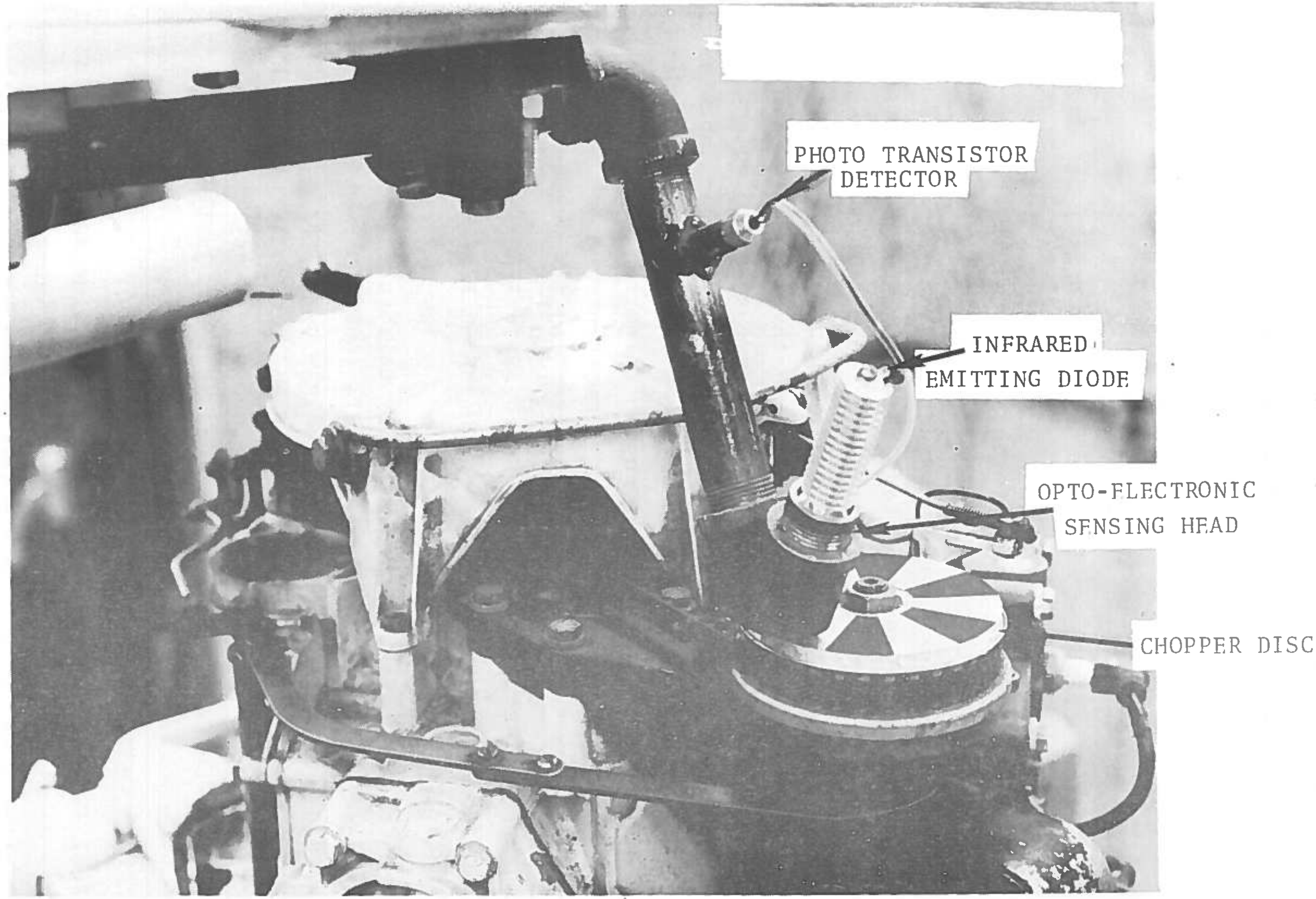


Figure 11. Opto-Electronic Engine Tachometer

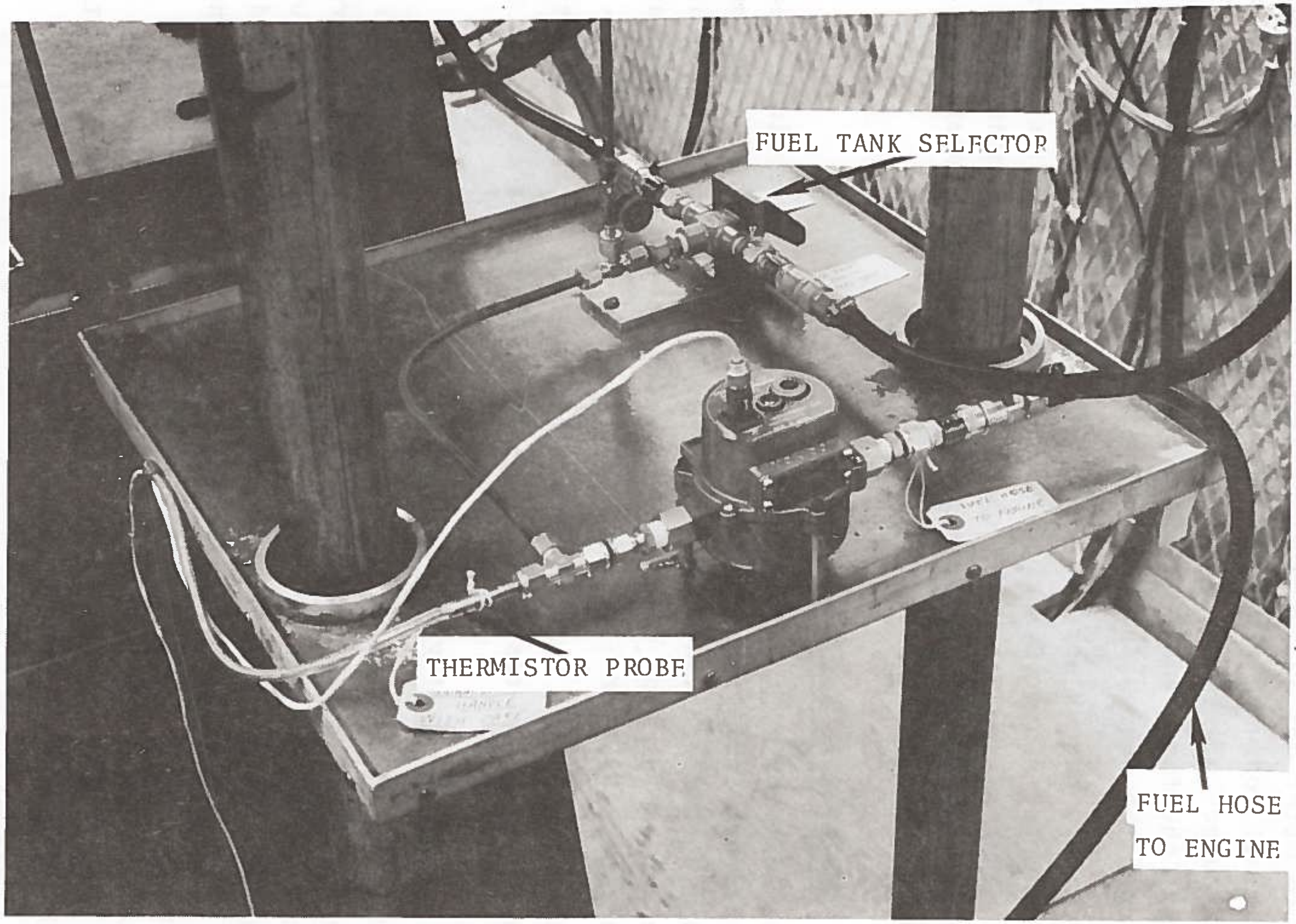


Figure 12. Fuel Flow Meter Set-Up

(Figure 2) mounted approximately 20 inches above the fuel flow meter to compensate for the pressure drop across the meter. The fuel flow meter has an integrating-type dial readout capable of reading fuel consumed within 0.001 gallons (~0.068 lbs.) with a rated accuracy of ± 1 percent. To assure accurate fuel flow readings, the fuel tanks were periodically weighed before and after each run series and compared with the flow meter readings.

Periodic checks were also made of the weighed fuel versus the flow meter measured fuel at one of the test engines operating modes. This assured accuracy over the complete operating capability of the OE. Generally, weighed and flow meter fuel consumption readings agreed within ± 2 percent.

2.4.3 Temperature Readouts

In addition to the tank water, lower unit and cylinder head temperatures, other temperatures were continuously monitored and recorded. These included carburetor inlet air, fuel temperature at the fuel meter, and dynamometer drain water. All temperatures were measured by thermistor probes that were calibrated daily.

The dry and wet bulb temperatures, as well as the barometric pressure inside the test cell, were recorded during each test run.

2.4.4 Engine Control Panel

The engine control panel (Figure 13) was located external to the test cell and contained all the necessary gages and hardware for monitoring and controlling the engine performance. Readouts of engine load, speed and operating temperatures were provided. Water flow meters and valves controlled the applied load to the dynamometer. An engine throttle control with turn-key engine starting (for engines with electric start) was located on the right side of the control panel, as well as an emergency ignition cut-off switch for rapid shut-down of the engine.

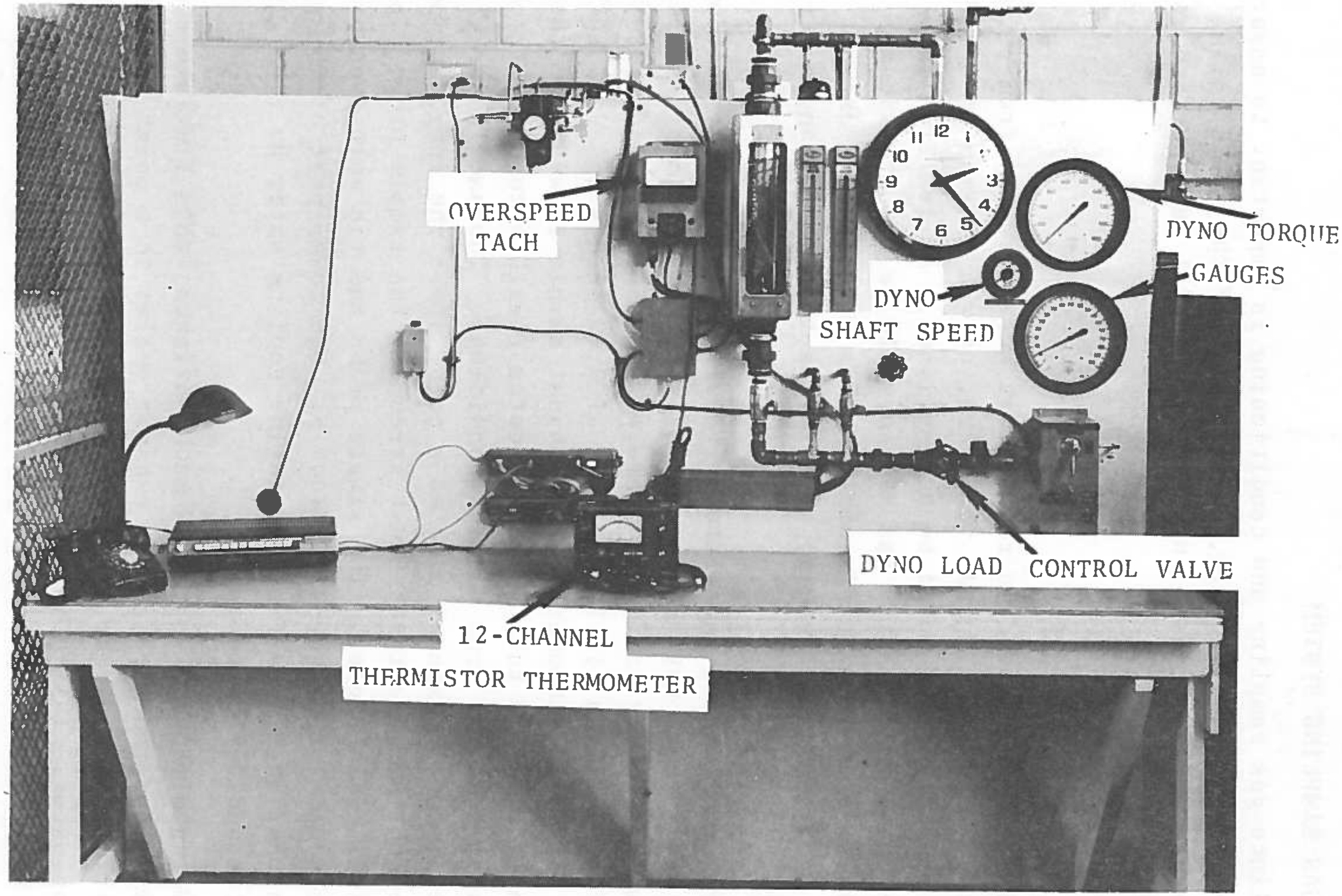


Figure 13. Engine and Dynamometer Control Panel

2.5 GAS SAMPLING SYSTEM

Since gas sampling and conditioning is important to assure a representative gas sample, each section of the gas sampling system and its associated instrumentation will be described in detail.

2.5.1 Gas Sample Probe

The engines tested in this effort were borrowed from private sources or the Coast Guard; therefore, only a minimum of modifcations to the engines could be accomplished. As drilling into the exhaust pipe to extract a gas sample would be too drastic a modification, two types of sample probes were used to extract a gas sample from the engine by going up through the engine exhaust outlet.

Figure 14 shows the probe originally developed for this purpose. This probe was constructed of a thin-wall stainless steel bellows with minor and major diameters, 0.25 inches and 0.38 inches, that fits inside a similar bellows of 0.40 inches and 0.60 inches inner and outer diameters. The exhaust sample flowed only through the small flexible tube while the outer flexible tube insulated the exhaust sample from ambient conditions. The sample was extracted from the exhaust pipe at a point above the introduction of engine cooling into the exhaust stream by the sample probe-tip with four radial holes. The sample probe and tip were oven-brazed to withstand temperatures to 1400° F. The lower part of the probe was further insulated from the engine cooling water by fiberglass, asbestos and teflon tapes.

Using mirrors, lights and much patience, this flexible sample line was inserted through the exhaust outlet to a point where the exhaust sample could be extracted without being mixed with engine cooling water. This point varied from a few inches to a foot below the OE power head depending on the test engine. Correct probe placement was verified by x-ray examination (Figure 15).

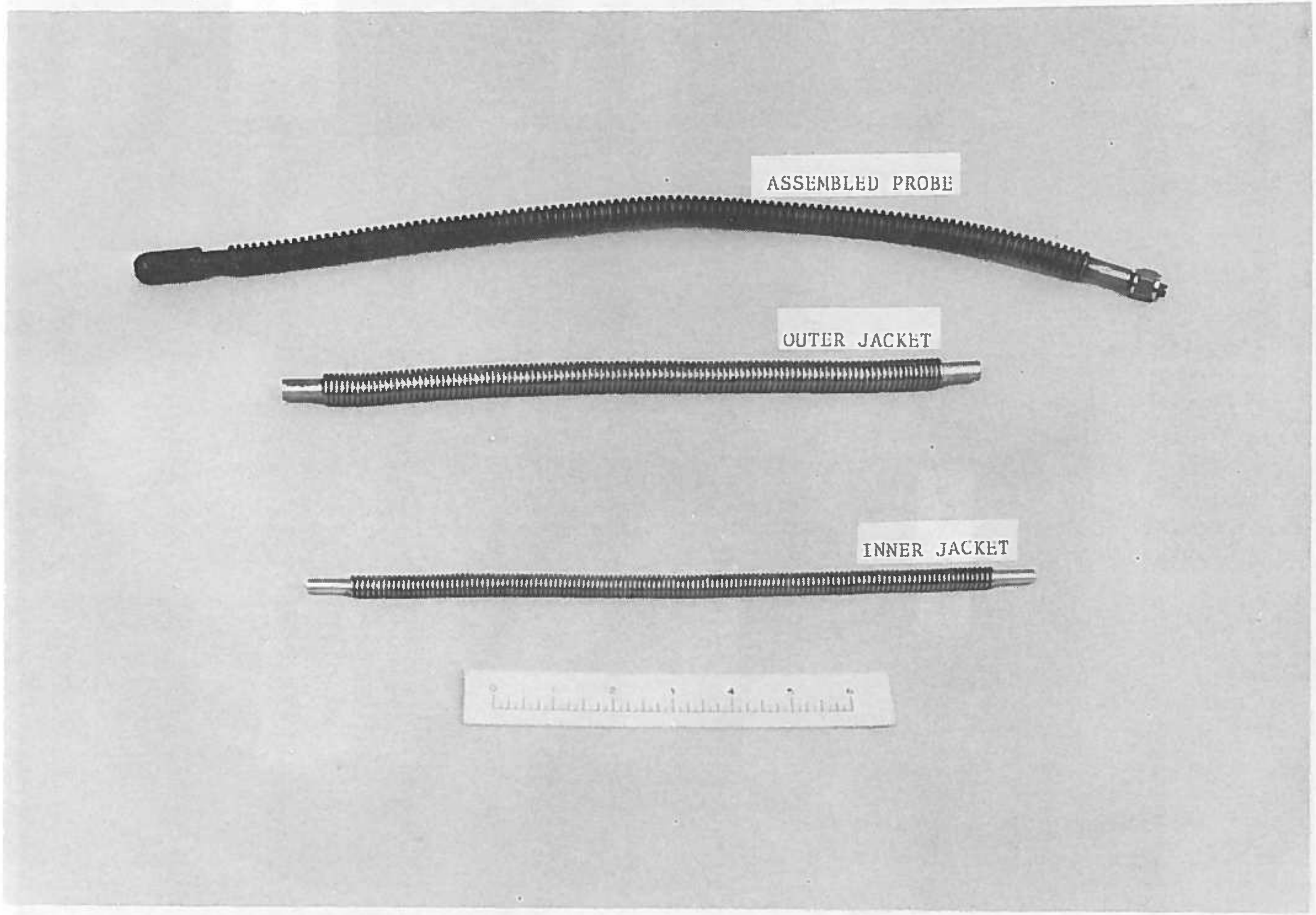


Figure 14. Exhaust Sample Probe with Major Components

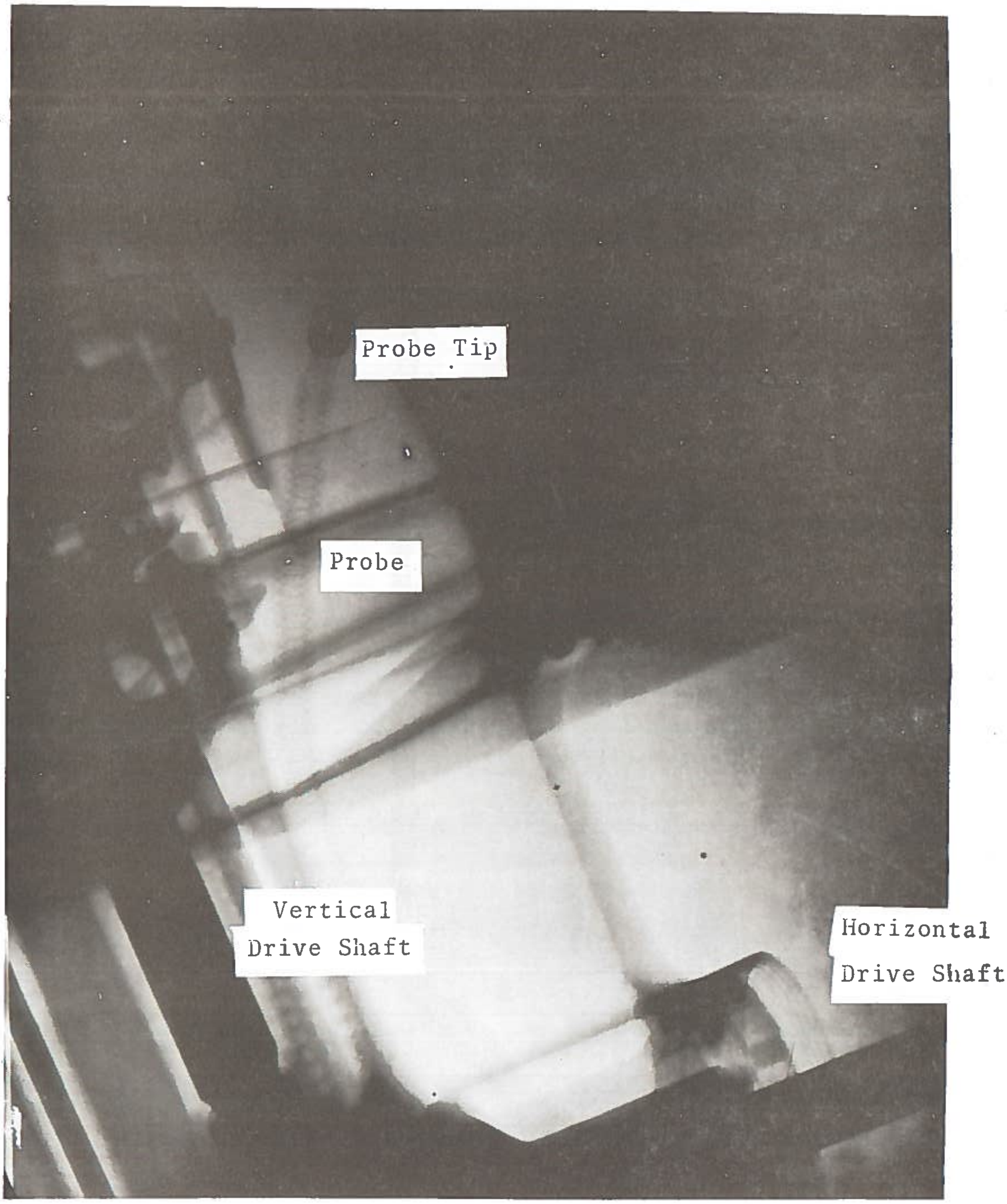


Figure 15. X-Ray of Mercury Engine (Side View)

Some heavy hydrocarbons are present in the two-cycle lubricating oil mixed at a ratio of 50 to 1 with gasoline. The dead space between the inner and outer flexible bellows in conjunction with the insulating materials kept the sample probe at a sufficiently high temperature to minimize the possibility of condensation of hydrocarbons on the inner walls of the probe and thus affecting results. Probe temperature measurements were performed on the 1959 Johnson 50 HP OE, using four thermocuples, each spaced 2 inches apart. These thermocouples gave a temperature gradient from 1100° F at the tip to 600° F at a point 8 inches below the tip.

Because of the difficulty of probe placement (especially with through-the-hub exhaust) and x-ray verification, and a tendency of the thin-wall bellows sampling tube to develop pin-hole leaks due to thermal stresses, another type of sampling probe was used later in the program. This second sample probe was 1/4-inch stainless steel tubing with the exhaust sample inlet end bent at right angles to the exhaust flow. The probe end had holes drilled into it to assure a representative gas sample if stratification was present. In order to position this probe, the OE power head was removed (a relatively simple procedure) and the probe inserted from the top of the exhaust pipe. The probe pick-up was approximately 1 inch to 2 inches below the power head exhaust outlet. As was the case with the flexible probe, asbestos, fiberglass, and teflon tape insulated the lower half of the probe from the cooling water. However, since no double wall construction was used, this lower part of the probe was also resistance-heated using the technique described in the next section.

2.5.2 Heated Sample Probe Extension

Both of the previously described sample probes were connected to a sample probe extension (Figure 16) of the same double-wall flexible-bellows construction. This extension carried the gas sample from approximately the engine exhaust outlet, through the tank water, to an external connecting point of the main sampling system. The extension was wrapped with asbestos, fiberglass, and

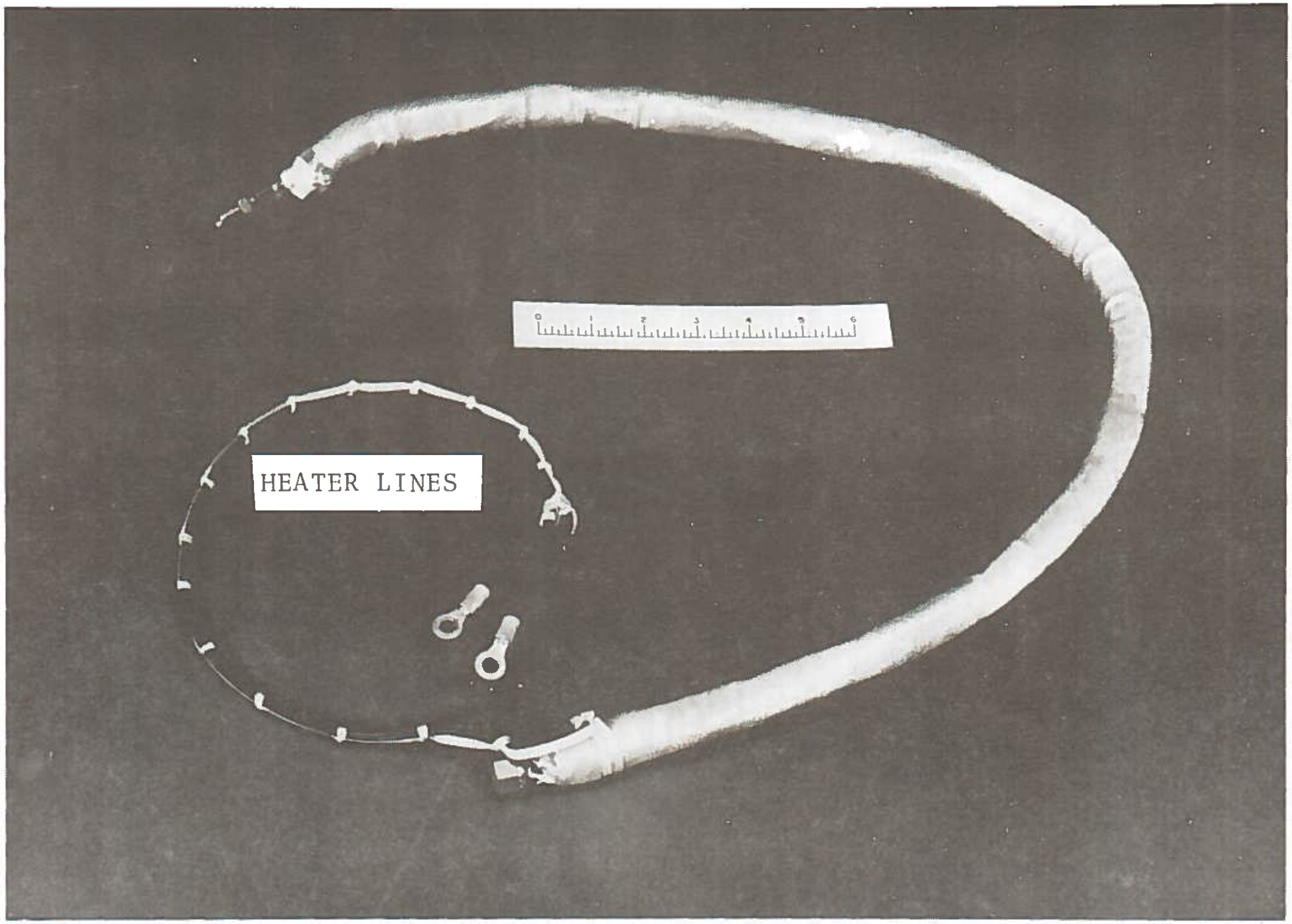


Figure 16. Heated Sample Probe Extension

teflon tape with a final outer layer of shrinkable tubing for water-resistance proofing. To counteract the cooling effect of the tank water, the probe extension was heated by current from a 40 amp, 6.3 v.a.c. variable transformer. A thermocouple sensor was "teed" into the center of the extension and its output measured by a temperature controller that switched the heated line on and off to maintain a minimum temperature of 250° F. When the 1/4-inch stainless steel sample probe was used, the portion of the line that was resistance-heated was extended at least one foot up the exhaust outlet of the OE.

2.5.3 External Sampling Lines

From the exhaust sample probe extension (Section 2.4.2), the sample line system (Figures 17 and 18) is divided through appropriate valving to either the water/exhaust mixing bubble tank (Section 2.7), or directly to the emissions measurement instrumentation. For direct sampling, valves V_2 and V_5 are closed, allowing the gas sample to pass through V_1 where the sample is divided between the heated and unheated sections (350° F). The heated section passes the sample through a particulate filter to a heated line and directly to the total hydrocarbon (THC) analyzer. The unheated section carries the gas sample through the proper conditioning elements to the carbon monoxide (CO), carbon dioxide (CO_2), oxides of nitrogen (NO_x) and oxygen (O_2) analyzers. (See Section 2.6).

To direct the gas sample through the bubble tank, valve V_1 is closed and valves V_2 and V_5 are opened. (Valve V_3 was open at all times except when filter F was being changed. V_4 was opened when the exhaust sample flow was directly to the emissions measurement instrumentation and it was necessary to maintain a flow on the bubble tank system.) The exhaust sample then flowed through valve V_2 to the particulate filter F-1. This filter protected the stainless steel bellows pump. Filter F-2 was a water trap used in case excess water of combustion was present in the exhaust sample. However, preliminary tests indicated that water was not present in quantities sufficient to affect the other elements of the system and this

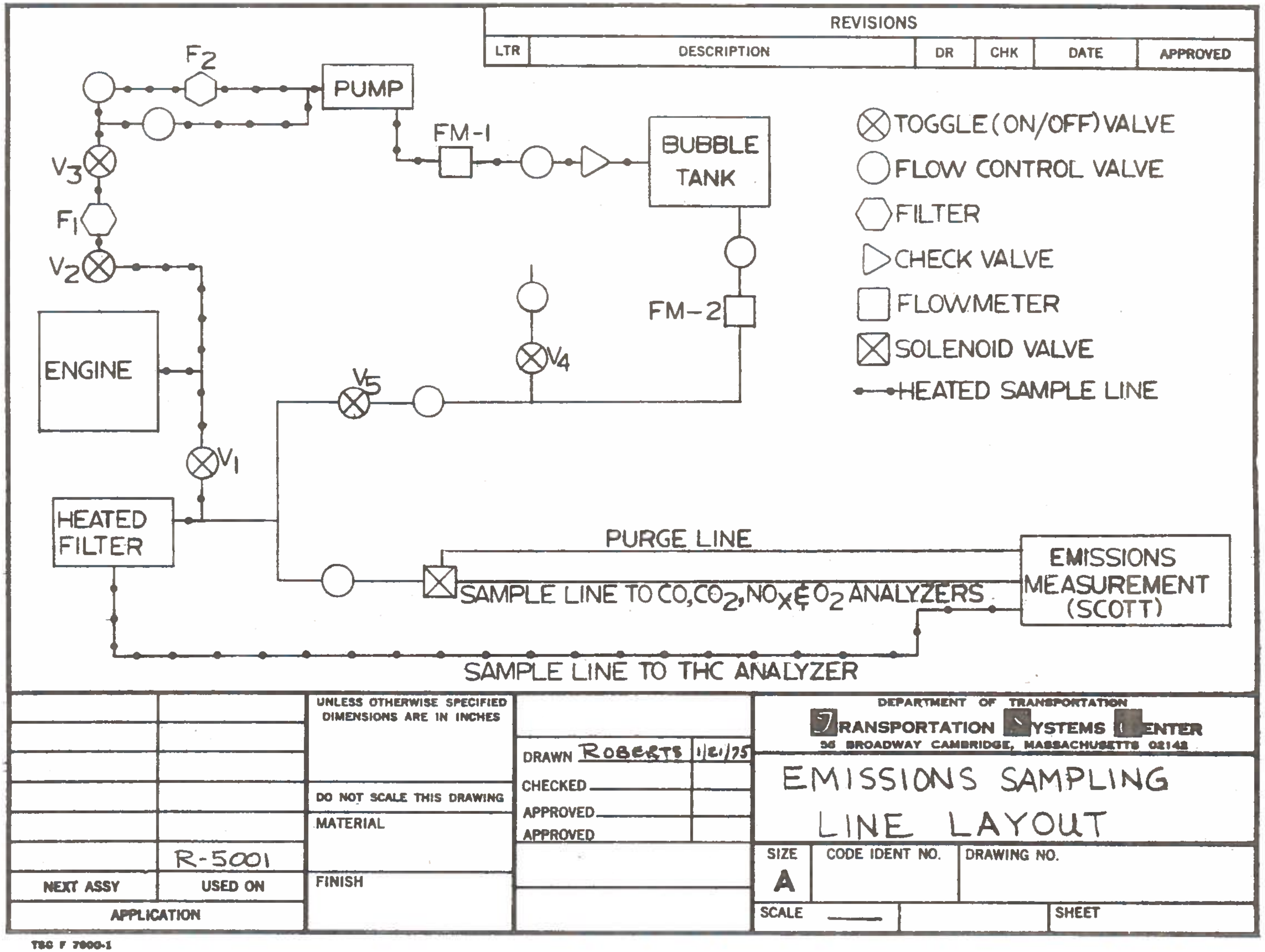


Figure 17. Emissions Sampling Line Layout

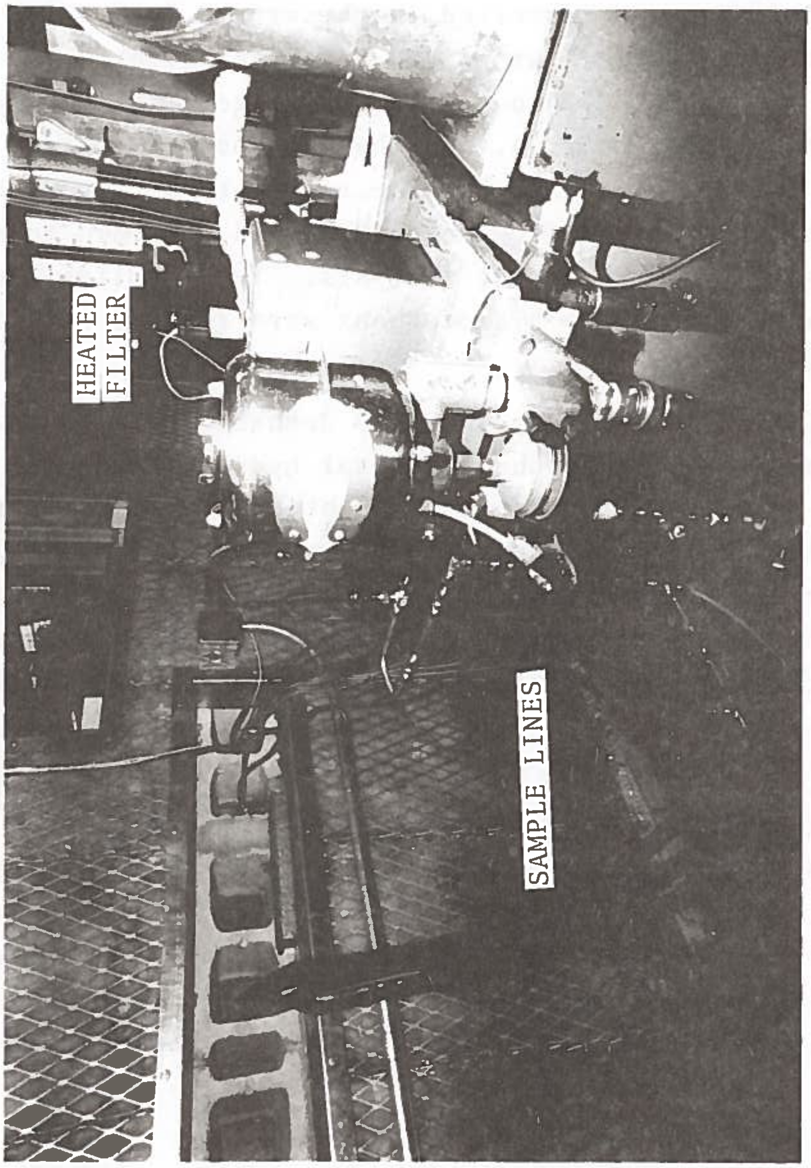


Figure 18. View of Sample Line System

water trap was not used. This minimized the possibility of any of the exhaust gases (especially NO_2) being lost to the water. The gas sample then passed through a flow meter (FM-1) to the flow control valve.

A check valve was installed in the system to prevent the bubble tank water from flowing back into the system. The gas sample was then bubbled through the tank water (the bubble tank is described in Section 2.7), and the scrubbed gas sample was drawn from the top of the tank. The sample then passed through a flow control valve and flow meter FM-2 and returned to the main sampling system for subsequent analysis. The sampling line was heated to assure that the hydrocarbons were removed only in the bubble tank.

A preliminary test with the 1959 Johnson 50 HP OE and cold sample probe and lines produced a total hydrocarbon (THC) concentration 10 percent less than that obtained when all lines were heated. The sample lines and valves that contact the gas sample (except for the various elements of the bubble tank) were made of stainless steel or teflon. A purge line that provided processed air for rapid clean-up of the exhaust sample was also provided.

2.6 EMISSIONS MEASUREMENT INSTRUMENTATION

The exhaust emissions measurement instrumentation is located external to the test cell in a caster-mounted cabinet (Figure 19). The theory of operation of this equipment has been described in a previous report (Reference 3). The measurement techniques, sampling conditioning, and specific problems encountered when measuring exhaust emissions from two-cycle OE's will be enumerated, however.

2.6.1 Specific Instrumentation

The gas species that were measured and the instrumentation contained in the cabinet are listed below:

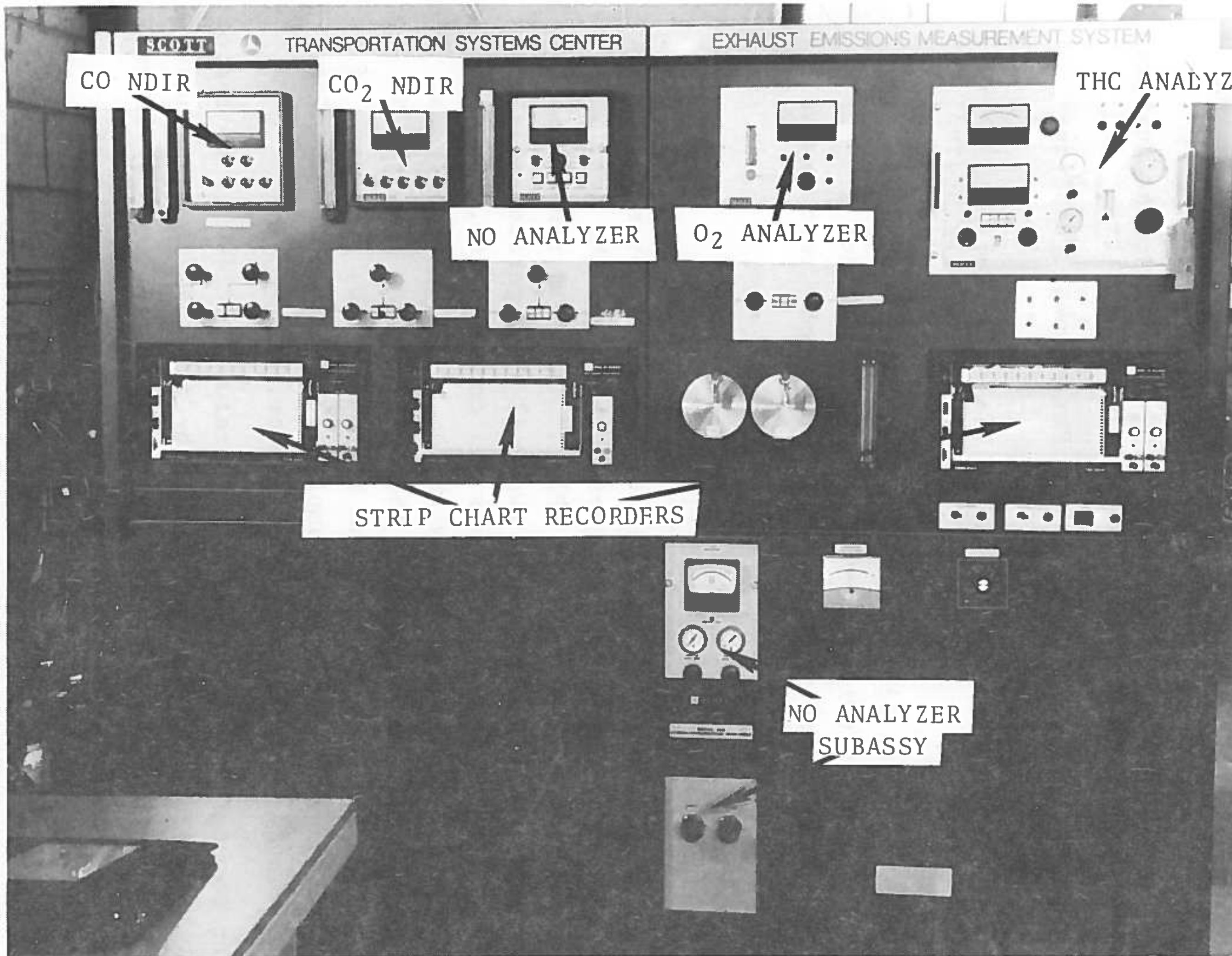


Figure 19. Exhaust Emissions Measurement Instruments

Gas Species	Instrumentation
Carbon Monoxide (CO)	Non-dispersive infrared analyzer (NDIR)
Carbon Dioxide (CO_2)	Non-dispersive infrared analyzer (NDIR)
Oxides of Nitrogen (NO & NO_x)	Chemiluminescence analyzer with converter
Oxygen (O_2)	Paramagnetic analyzer
Total Hydrocarbons (THC)	Flame ionization detector (FID) (totally heated)

The instruments listed above provided data on a real-time basis. The exhaust emissions cabinet also contained all the necessary plumbing and fixtures to assure proper test sample conditioning and handling.

2.6.2 Exhaust Gas Sampling Conditioning

Figure 20 is a flow schematic of the emissions measurement system. The heated sample line goes directly to the totally heated Flame Ionization Detector (FID). The cold sample line passes through a pre-filter to a two-coil refrigerator maintained at 32° F. The refrigerator removes all condensables, especially water vapor, that may interfere with the subsequent analysis. One coil of the refrigerator removes the condensables from the NO sample; the other coil treates the CO, CO_2 and O_2 samples. If NO_x is to be measured, the gas sample flows through a stainless steel converter prior to the refrigerator.

The converter was held at a temperature of 1400° F to reduce all NO_x to NO for subsequent analysis by the chemiluminescence analyzer. The gas sample then flows through particulate filters to stainless steel bellows pumps. The flow rate is set by appropriate flow meters and valves prior to analysis by the appropriate instrumentation. Both the CO and CO_2 NDIR analyzers are heated to approximately 130°F to eliminate the possibility of water vapor condensing on the NDIR optics.

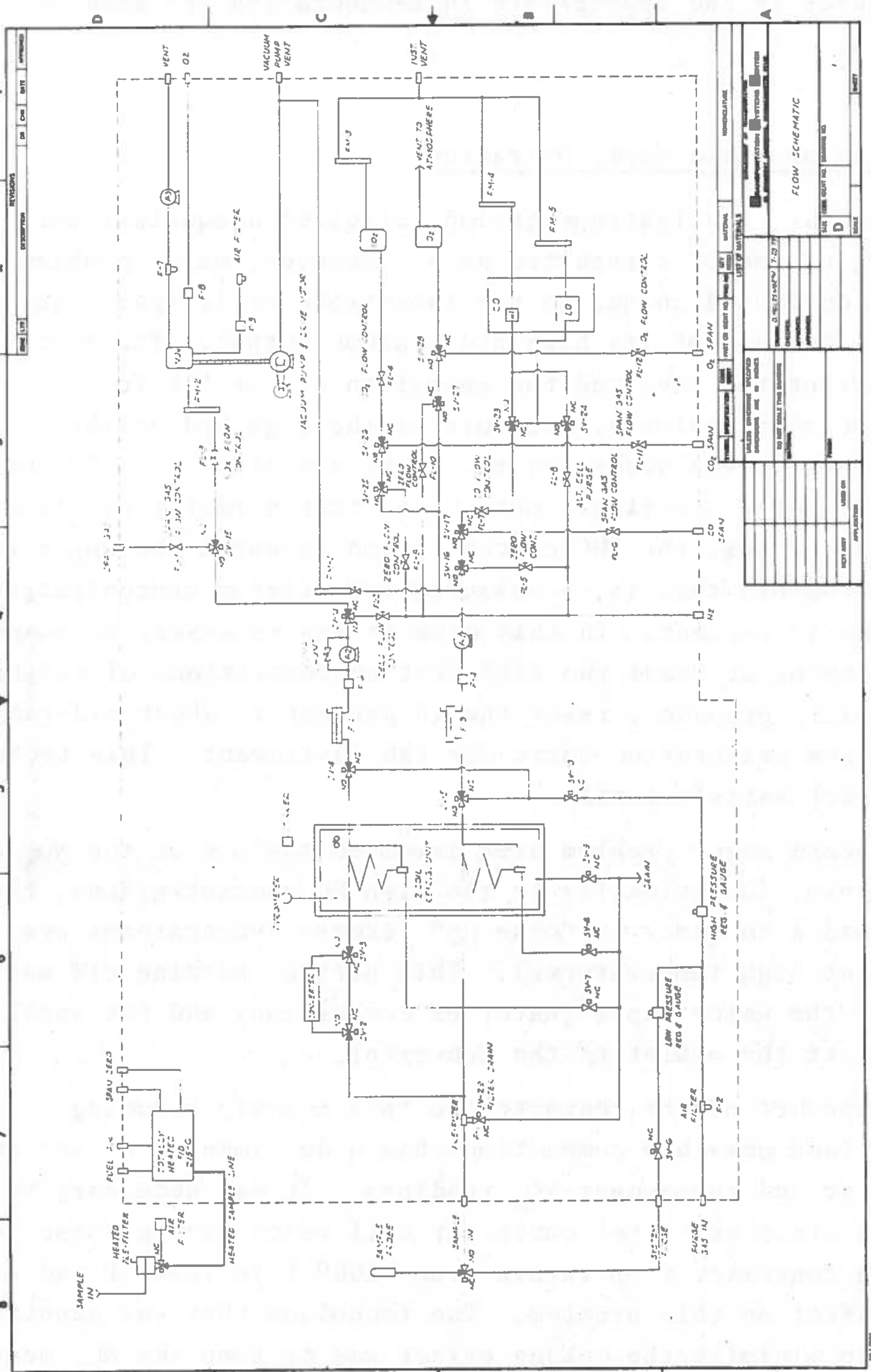


Figure 20. Flow Schematic for Emission-Measuring Instrumentation

The system also provides the capability of introducing zero and span gases to the appropriate instrumentation for ease of calibration.

2.6.3 Emission Measurement Operation

In general, the instrumentation performed adequately for the testing of the OE's reported here. However, major problem areas are considered unique to the two-stroke cycle spark-ignition engine because of its high hydrocarbon output. The first problem encountered involved the operation of the FID for total hydrocarbon analysis. Because of the high hydrocarbon concentrations it was necessary to remove and clean the FID burner and sintered metal prefilters more often than normally required. Also, in some cases, the THC concentration exceeded the upper range of the instrument; that is, a measured hydrocarbon concentration greater than 10 percent. In this case it was necessary to respan the instrument using at least two different concentrations of calibration gases (normally propane), reset the 10 percent to about mid-range and draw a new calibration curve for the instrument. This technique seemed to work satisfactorily.

The second major problem area involved the use of the NO_x converter. Again, due primarily to the high HC concentrations, the converter had a tendency to "coke up" (excess hydrocarbons are burned off at high temperatures). This partial burning off was verified by the water vapor (water of combustion) and the smell of burned fuel at the outlet of the converter.

The exposure of the converter to this heavily reducing atmosphere (and possible combustion) had a detrimental effect on the converter and subsequent NO_x readings. It was necessary to replace the stainless steel converter coil twice during these tests. Varying the converter temperature from 1200° F to 1600° F had a marginal effect on this problem. The technique that was eventually developed to minimize the coking effect was to keep the NO_x measurement time to a minimum and between measurements flush the converter with air and periodically with pure O_2. A periodic calibration of the converter was performed. However, even with these precautions, if the time between sample runs was not adequate for the converter to recover, inaccurate NO_x readings were obtained. It should be emphasized that this converter problem did not affect the accuracy of the NO readings. Generally, enough test runs were made with each engine so that at least one accurate NO_x reading was obtained in each operating mode.

2.7 EXHAUST/WATER CONTACT SYSTEM

As previously mentioned, since the exhaust of an outboard engine is released below water level, a system was designed and built to study the effects of water scrubbing on the exhaust emissions from these engines. The system that was built is similar to that used by Southwest Research Institute (SWRI) (Reference 1) with some modifications that contributed to ease of operation. It was decided to maintain this basic similarity to compare results. It is not claimed (SWRI agrees) that this system simulates exactly the real-world conditions encountered by OE exhaust. However, it did offer a systematic approach in which many of the variables could affect the scrubbing process, such as mixing rates, water temperature and PH, water pressure, and flow rates could be controlled or measured.

A flow schematic of the exhaust/water contact system is shown in Figure 21. Supply water was introduced into the system through a flow control valve V_1 and a water flow meter FM-1. Water flowed through a float controlled by valve V_2 into a level control tank T. The level control tank consisted of a 12" x 24" plexiglass tank whose long axis was parallel to the floor. The water from this tank fed the bubble tank where it was mixed with the exhaust gas. The bubble tank was also plexiglass and similar in dimensions to the level control tank. However, the bubble tank had its long axis perpendicular to the floor. A 15-inch high plexiglass divider in the middle of the tank acted as a weir to assure that the water through which the gas sample was bubbled did not recontaminate the incoming fresh water. The exhaust sample and

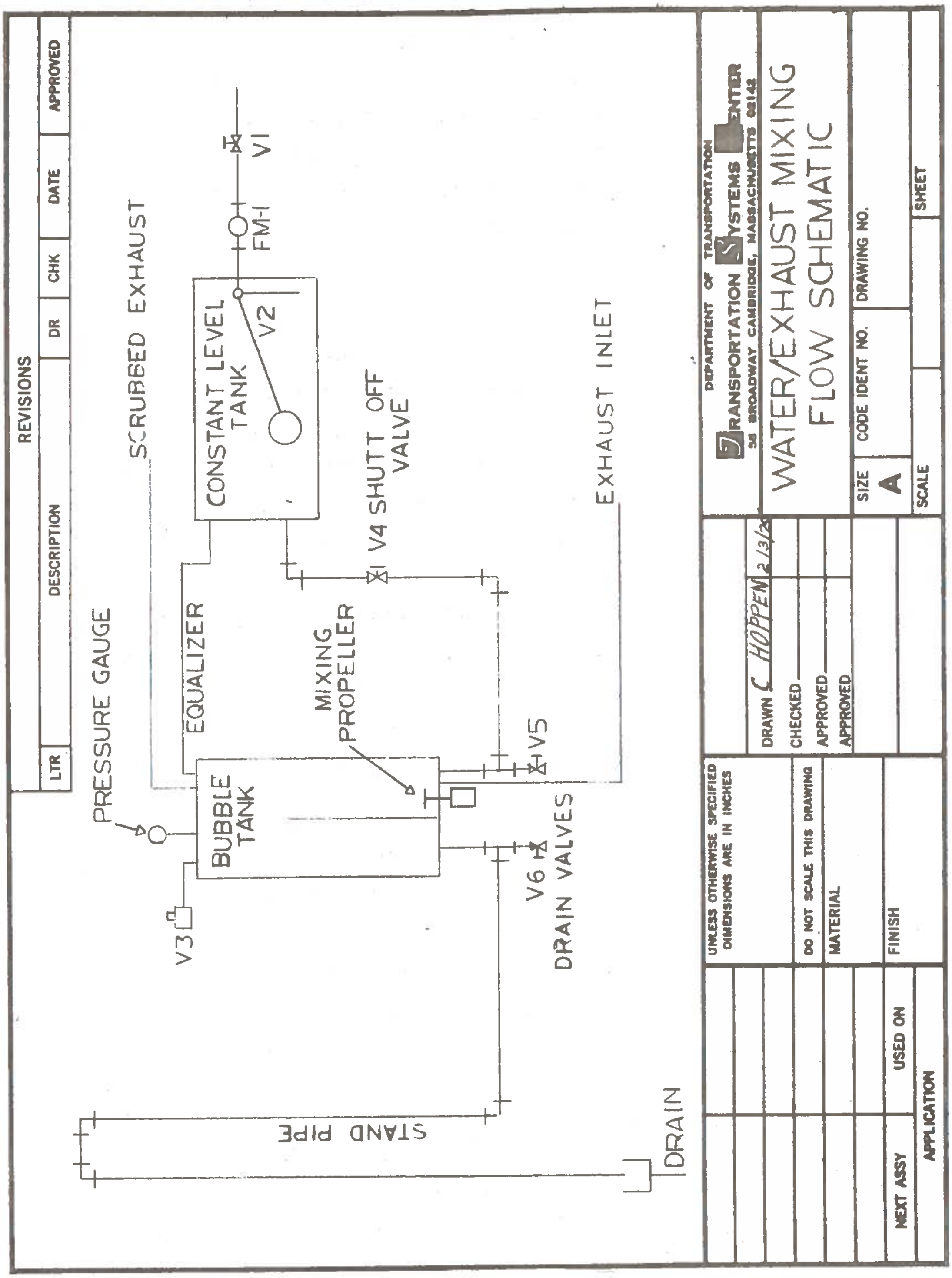


Figure 21. Water/Exhaust Mixing Flow Schematic

fresh water sample were mixed on one side of the weir, and the now contaminated water flowed off the top of that side over the weir to the opposite side. The water flowed up a 65-inch stand pipe that, in conjunction with a variable pressure regulator relief valve V_3, maintained a pressure head on both tanks of 65 inches.

The raw exhaust sample entered the bubble tank through the exhaust system previously described (Section 2.5). Additional mixing of the exhaust sample was achieved by an engine-driven propeller (1800 rpm) located at the base of the tank. The exhaust sample, after water scrubbing, was extracted from the top of the bubble tank to the emissions measurement instrumentation. Figure 22 shows an exhaust sample being introduced through the water/exhaust scrubbing system.

2.8 ENGINE TESTS

The experimental procedures followed in the OE test program are described in detail in this section.

2.8.1 Engine Fuel and Lubricating Oils

The gasoline used in these tests was the controlled standard fuel Indolene 30 and conformed to Federal emission test fuel specifications.

The lubricating oil mixed with the test fuel was the OE manufacturers product recommended for these engines and conformed to BIA (Boating Industry of America) standards for TCW service. The oil was mixed at a 50:1 gasoline:oil ratio for all tests as this ratio is now recommended by the manufacturers for use in all OE's. The only exception to this was during the break-in period of the new 40 HP Mercury engine. Per manufacturers recommendations, the lubricating oil was mixed with the gasoline at a ratio of 25:1. (No emissions measurements were performed during this period.)

Fuel temperatures were recorded and density measurements were corrected, if necessary. However, it was found that the fuel, as it was stored inside, was normally at constant ambient temperatures.

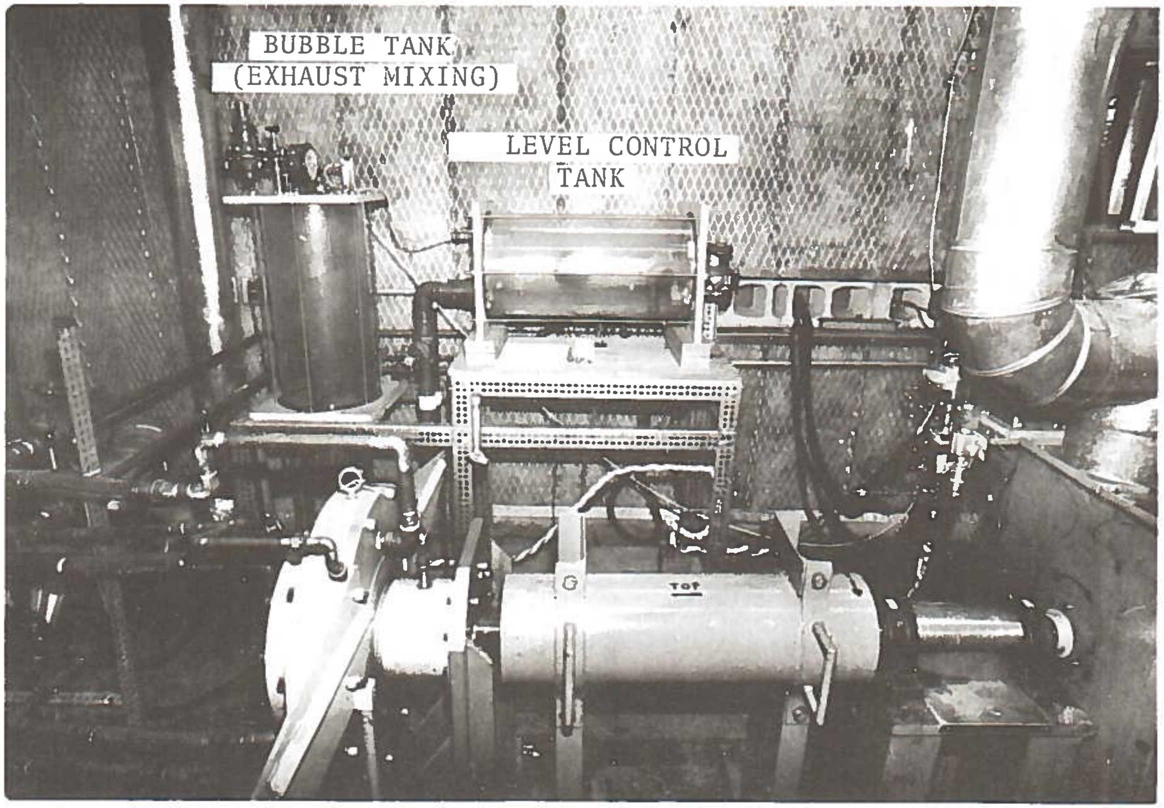


Figure 22. Exhaust Emission Bubble and Level Control Tanks

The fuel was measured out by volume and weight in the fuel preparation room (Figure 23) and the correct amount of lubricating oil added and thoroughly mixed. The fuel/lube-oil mixture was then poured into the 6-gallon fuel tank and carried into the test cell. The fuel tank was primed and the air was bled from the system by a valve provided for that purpose (Figure 12).

For long tests, a second fuel tank was provided that could be primed and cut in (by the use of a two-way valve) without engine shut-down. Small amounts of leftover fuel were drained from the boat tanks and discarded before a fresh supply of fuel/oil was mixed into the tank.

2.8.2 Engine Preparation

When an engine was received for testing, it was thoroughly inspected for broken or disconnected mechanical and electrical parts. On older OE's, the lower unit gear-case oil was drained and replaced with the manufacturers' specified oil. All grease fittings were lubricated per factory specifications.

For the last three engines tested, the power head was removed for gas sample line-probe placement. After the power head was replaced, the probe position was verified by x-ray if necessary. The engine was again given a thorough visual inspection. The powerhead shroud was left off so that the tachometer chopper could be applied to the flywheel. The engine was then mounted on the test stand and all electrical, fuel line, and diagnostic connections were made while the OE propeller shaft was aligned with the dynamometer drive shaft.

The engine was then started in neutral and allowed to idle until the engine operating temperature was stabilized. During this time all equipment was checked and a preliminary emissions test was made to assure that all emissions instrumentation was operating properly and no leaks were present in the sample lines. (Leaks were indicated by lower than normal CO, CO_2 and NO and higher than normal O_2.) The OE was slowly accelerated in neutral to check engine performance and operating parameters. OE's generally are

Figure 23. Fuel Storage and Preparation Room

equipped with a shift detent interconnected with the throttle so that the engine speed in neutral cannot exceed 1500-2000 rpm. This feature assures that engine speed cannot exceed rated speed (in neutral, no load) and do permanent damage to the engine.

Upon completion of these preliminary tests, the engine was shut down, the tank water drained and the engine alignment checked to assure that the OE had not moved because of vibration, mechanical stresses, etc. All jack-screws and connections were tightened, if necessary.

2.8.3 Emissions Testing

Upon successful completion of the preliminary tests, initial emissions test runs were made. The OE under test was run in neutral at idle speed (normally 600-800 rpm) until stabilized engine operating conditions were obtained. The engine was then put in gear and the necessary loads (as per Table 2) applied for the particular engine under test. The engine speed and load were slowly increased until these requirements were met. While changes in engine power setting were being made, the emissions instrumentation were zeroed and calibrated using the appropriate gases. The engine was allowed to stabilize at the particular power setting under test for at least five minutes. Simultaneous emissions and fuel consumption were taken. The emissions data were recorded continuously on strip-chart recorders (along with zero and calibration data). Each power mode was held at least ten minutes (more often 15-20 minutes) after stabilization. During this time, emissions and fuel consumption were continuously measured. Fuel-flow data were integrated over time intervals of five or ten minutes during the emissions tests. Multiple readings of fuel consumption were taken to assure consistency. The emission measurements at a power setting were closely monitored to assure stable operation and reproducible results. A typical strip-chart recording for CO and CO_2 at one power setting is given in Figure 24. Other important engine-operating parameters, such as torque, speed, temperatures, etc., were recorded on test sheets (Figure 25).

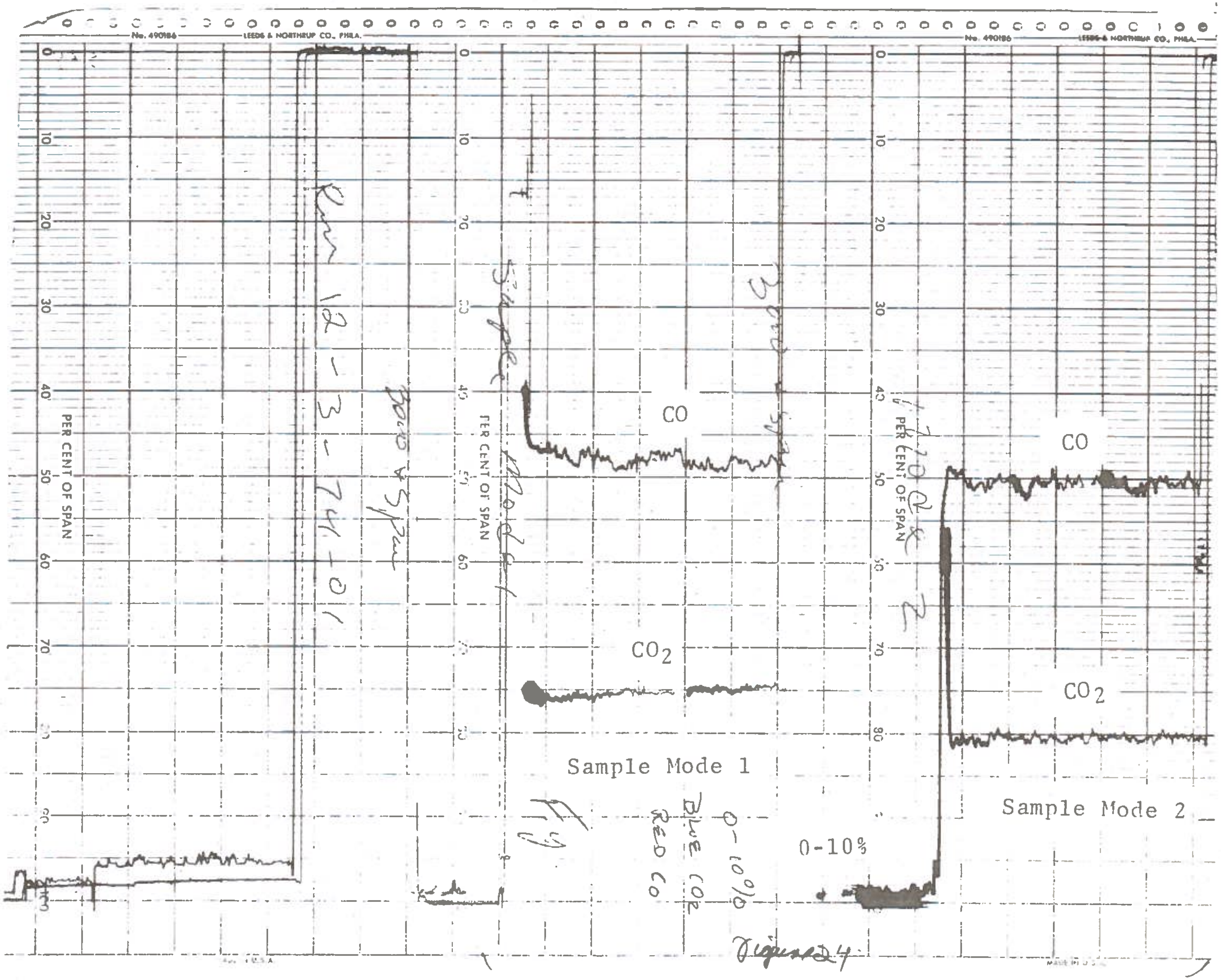


Figure 24. Typical Strip-Chart Recording for CO and CO_2 at One Power Setting

COAST GUARD ENGINE TEST DATA

Date: 11/22/74 Run #: 01

ENGINE DATA

Year: 1972

Manufacturer: MERCURY

Horsepower: 40

Serial #:

ENGINE HISTORY

Total Operating Hrs.:

Operating Hrs. Since Overhaul :

Operating Hrs. Since Tuneup :

	ENGINE										METEOROLOGICAL				BUBBLE TANK				
		RPM				Temperature					Temp								
Run Number	Time	Eng.	Dyno	Torque	H.P.	Cyl	~~Carb Air~~ FUEL	~~Dyno~~ TANK WTR	Lwr Unit	Fuel /Min	Dry	Wet Bulb	Bar. Press.	Rel. Humid.	Water Flow G.P.M.	Exhaust Flow SCFH	Prop On ?	Type of Bubbler	Comments
1	14:50	800	400	—		73	<70	<70	<70		68	52	30.00						RUNS BEAUTIFULLY
2	15:05	1000	450	40		74	<70	<70	<70										
3	15:13	2000	1050	95		75	<70	<70	<70										
4	15:25	3000	1550	191		80	<70	70	<70		67	51	30.08						
5	15:35	4000	2075	320		82	<70	81	<70										
6	15:47	5000	2600	460		85	<70	81	<70		68	51	30.08						
7	16:02	800	350	—		83	<70	<70	<70										
8						SHUT OFF		AT 16:15											
9																			
10																			
11																			
12																			
13																			
14																			
15																			
16																			

Figure 25. Typical Test Sheet Showing Torque, Speed, Temperatures, Etc.

Each engine-power setting was called a mode. The test runs were usually performed in sequence from idle to full power. For example, on the 1962, 70 hp Mercury, mode 1 was idle, 700 rpm; mode 2 was approximately 1 hp at 1000 rpm, etc. Some initial tests were taken to assure that the sequence of the test runs had no effect on the test results. That is, the same results should be obtained if the test run was from low to high power or high to low power.

When test runs were performed using the exhaust/water contact system, the runs through the bubble tank were designated "A" runs and were performed sequentially with the runs measuring the exhaust products straight from the engine. In other words, the sequence of tests would be: mode 1 idle, mode 1A idle through bubble tank and generally briefly back to mode 1, then mode 2, mode 2A, etc. In this way the effects of the exhaust/water scrubbing would be compared only with the untreated exhaust measurements taken in the same test run. It was noted that when a test run was taken through the bubble tank, it required at least 5 to 15 minutes for the readings of the exhaust emissions instrumentation to stabilize. This was caused by the bubbled exhaust products displacing the air trapped at the top of the bubble tank. The exhaust emissions were monitored continuously during this time and measurements were taken only after the emissions stabilized. A typical CO and CO_2 strip-chart recording after water scrubbing is shown in Figure 26. Each test run required 1-1/2 to 2-1/2 hours of engine operating time.

2.8.4 Operating Mode Stabilization

As previously mentioned, the OE under test was allowed to stabilize for at least five minutes at each operating mode before emissions measurements commenced. In general, there was very little drift in engine speed or load once the OE stabilized. However with the majority of OE's, there was a midspeed range (approximately 3000 rpm) at which stabilization was extremely difficult. In the cases where the speed-load drift was such that valid emission measurements could not be taken, the engine speed was varied approximately 100 to 200 rpm until stable

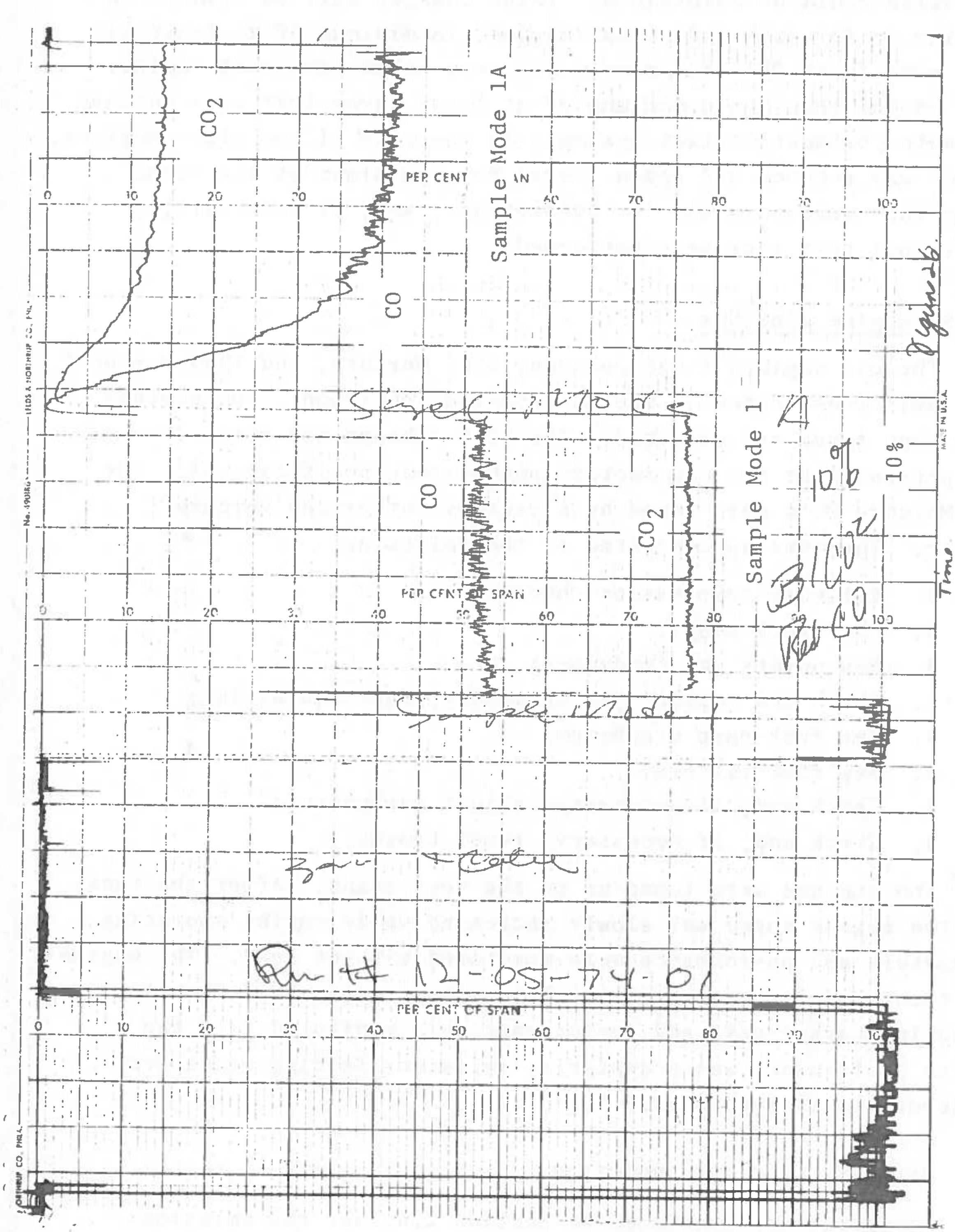


Figure 26. Typical Strip-Chart Recording for CO and CO_2 after Scrubbing

operation could be maintained. These changes will be evident in Section 3 for each individual engine. A minimum of at least six test runs (most OE's had many more) were taken with each engine. Each engine then had a minimum of at least three test runs through the water/exhaust contact system. In the case of the older engines, the OE was retuned and again tested for a minimum of six runs. These runs were compared for consistency, and, if necessary, additional test runs were performed.

2.8.5 Engine Tune-Ups

The old engines (1959 Johnson, 1962 Mercury, and 1965 Mercury) were emissions-tested in the as-received condition. The engines were then tuned and retested. The 1959 Johnson was retuned by TSC personnel as per OMC factory authorized specifications. The two Mercury OE's were tuned by a factory-authorized Mercury dealer. The tune-up consisted of the following:

1. Cylinder compression check;
2. New spark plugs;
3. New points and condenser;
4. Check and replace, if necessary, ignition wiring;
5. New fuel-pump diaphragm;
6. New fuel filters;
7. Check and, if necessary, adjust carburetor;
8. Check and, if necessary, reset timing.

The engines were tuned-up on the test stand. After the tune-up, the engine speed was slowly increased while engine operating parameters and performance were monitored without load. The engine was then placed in gear and the load slowly applied while emissions, operating parameters, and performance were monitored. If the engine performance was acceptable, emissions testing proceeded as described in Section 2.8.3.

2.9 DATA HANDLING AND REDUCTION

As previously mentioned in Section 2.8, all raw emissions concentration data was recorded on strip-charts; other pertinent engine data of speeds, load, temperatures, fuel flow, etc., were recorded on separate log sheets. These data were then manually combined on a work sheet. Emission concentration levels as a function of speed and load were extracted from the strip-charts and corrected for zero or calibration variations. For the CO and CO_2 NDIR analyzers, the response was not linear over the full scale operating range of the instrument. In this case, correction curves were used to change the strip-chart raw data to actual concentration data. Torque readings were corrected with the torque calibration curve (Figure 10) and actual engine horsepower calculated. The fuel-flow readings were converted from gal/hr to lb/hr using the correct density values. The brake specific fuel consumption (BSFC) in lb/bhp/hr was also usually calculated at this time. All emissions, fuel consumption, and engine operating parameters were tabulated with engine test number and operating mode. These working sheets were used for input of the data into the computer for final data reduction.

2.9.1 Computer Data Reduction

Computer data reduction converts the raw emissions concentration information to mass emission information using standard equations based on the carbon balance technique.

2.9.1.1 Carbon Balance Technique - The carbon balance technique computes the mass emissions from the raw concentration data based on the fact that a mole of hydrocarbons in the exhaust measured as carbon must have originated from one mole of fuel of formula C_xH_y. Therefore, the prerequisites for using this technique are that all carbon-bearing constituents of the exhaust must be measured and the hydrogen-to-carbon mass ratio of the fuel must be known.

To use the carbon balance technique all concentration measurements must be reported on either a "wet" or a "dry" basis. All corrected concentration measurements include intake air humidity and water of combustion. The basis of measurement must be consistent for all species.

As previously mentioned in Section 2.8, a refrigerator was used to remove all water vapor for the CO, CO_2, NO, NO_x and O_2 measurements. This water vapor was replaced so that all emissions concentrations were on a "wet" basis (THC are measured on a "wet" basis). Equations that performed this correction were developed. It was necessary to measure the dry bulb/wet bulb temperatures and determine the water content of the air (percent by volume). The correction equations are:

$$Cw = Cd \frac{200-y(2.055)}{200-6 + Cd(1.055)(1-CO\%/100)} \quad (1)$$

where Cw = wet concentration and Cd = dry concentration.

$$Cd = \frac{100}{100 + 1.055(CO\% + CO_2\%)} \quad (2)$$

y = % volume of water vapor in the intake air.

These corrected "wet" concentrations were then used in the following carbon balance equations to obtain the fuel specific mass emissions (M) in lbs/hr. F is the fuel rate in lbs/hr.

$$\text{Total carbon (TC)} = CO\% + CO_2\% + HC\%$$

$$\begin{aligned} M(CO)\ (lbs/hr) &= 1.98\ (CO\%)F/TC \\ M(CO_2)(lbs/hr) &= 3.11\ (CO_2\%)F/TC \\ M(NO_x)(lbs/hr) &= 3.26\ \frac{(NO_{x\,ppm})F/TC}{10^4} \\ M(THC)(lbs/hr) &= (HC\%)F/TC \end{aligned} \quad (3)$$

The constants (1.98, 3.11, 3.26) are based on the atomic weights of hydrogen, carbon, the components of the exhaust being calculated, and the hydrogen-carbon ratio of the test fuel.

The fuel-to-air ratio (F/A) may also be calculated using similar equations:

$$F/A \quad \frac{TC}{207 - 2(CO\%) - CO_2} \quad (4)$$

It should be realized that the calculated F/A ratio for a two-cycle engine with large amounts of unburned fuel is not exact, but is given here for comparison and trend purposes only. Brake specific mass emissions can then be calculated by dividing each of the fuel specific mass emissions by the hp at that operating mode.

2.9.1.2 Computer Program - A computer program was developed that performed the calculations in the previous section and presented the results in a usable format. A flow diagram for this program is given in Figure 27.

A data set was stored in the memory by number. The run number was then coded by month, date, year, and the sequential run of that day. For instance, Run Number 01-01-75-1 was the first run on January 1, 1975. After entering the run number, the computer searches the memory for a similar run number. If the run number is unique, the program progresses to the data input. If the run number is already stored in memory, a copy of the data may be obtained, a new file started, or new data may be entered on the old file.

Engine information was then typed into the program. This information included manufacturer, model number, year, hp, serial number, etc. This data and other important engine operating parameters were then entered into the program. The data was corrected from "dry" to "wet" and the fuel/air and air/fuel ratios calculated and printed-out. The emissions were then calculated and printed out for mass (lb/hr, kg/hr), brake hp (lb/hp/hr, kg/hp/hr), and fuel specific emissions (lb/1000 lb of fuel). Also calculated and printed out are the kg/TM (mass emission rate/turned mile based on the propeller pitch) and the percent of fuel unburned. The percent of fuel unburned is the mass emission rate (lb/hr) of the THC divided by the fuel rate (lb/hr) x 100 percent. After printout, all data was stored by run number in the computer memory for subsequent analysis or comparison. Table 3 is a sample print-out for one run.

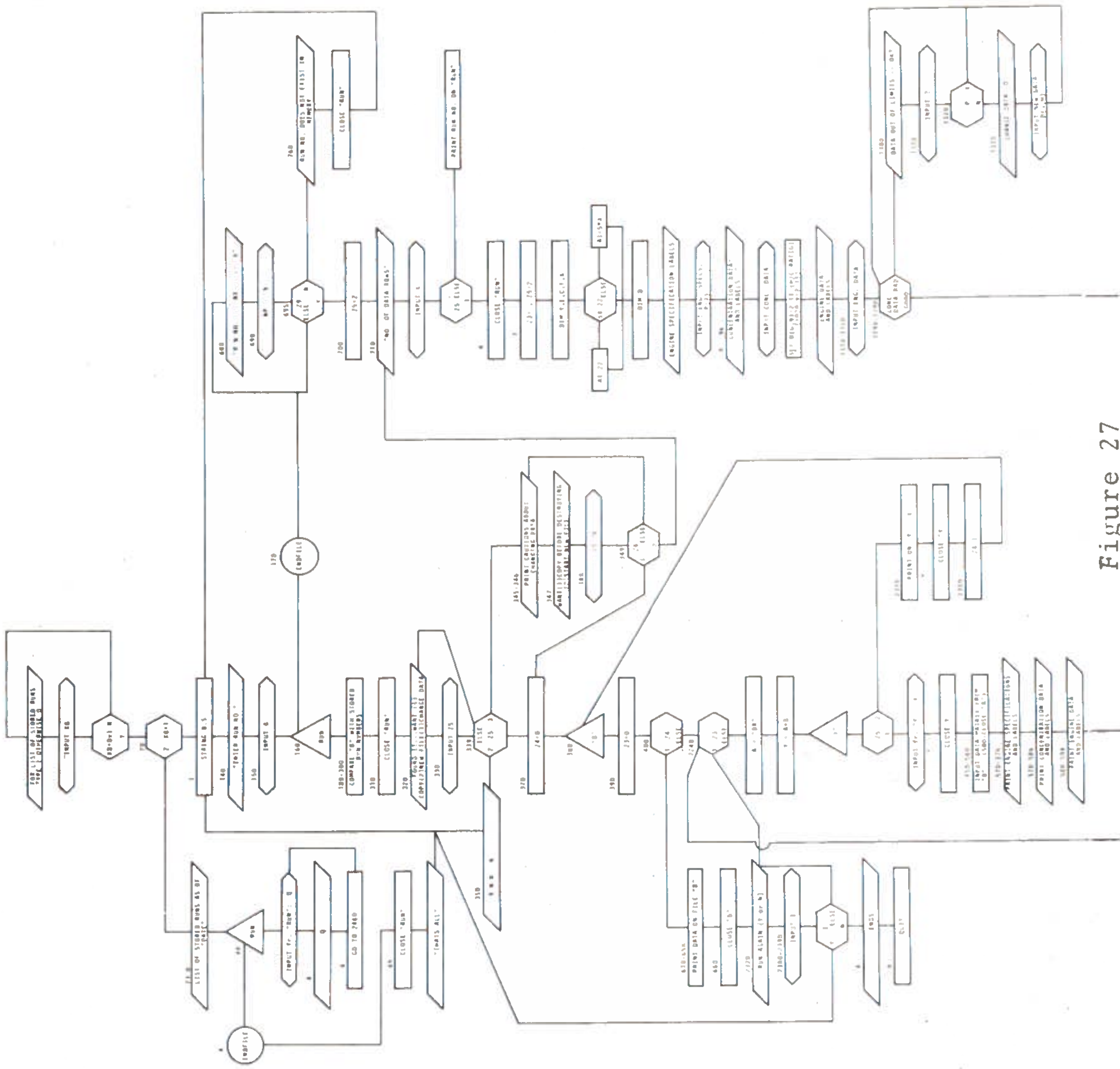


Figure 27

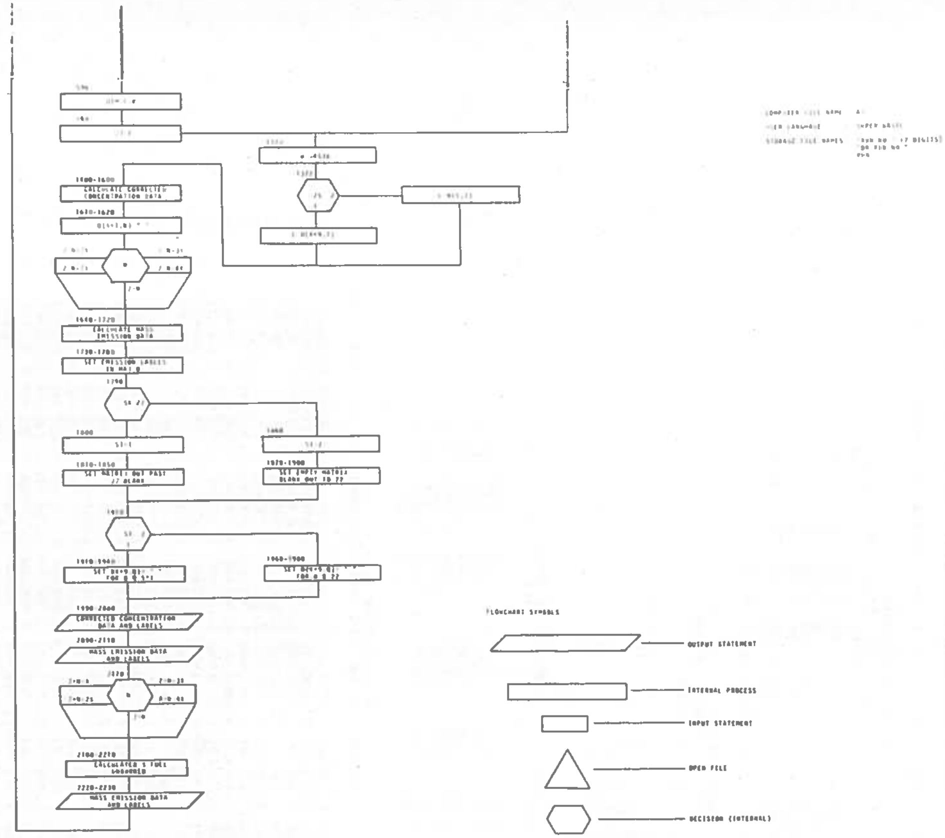


Figure 27. Computer Program Flow Diagram

TABLE 3. SAMPLE PRINT-OUT

```
ENTER RUN NO.? 1122741
FOUND IT! . . . YOU WANT (1) A COPY OF DATA
                         (2) TO START NEW FILE
                         (3) TO INPUT NEW D
? 1
  MFR    MODEL    YEAR*NOM HP*DRAINLESS?*SERIAL NO*REDUCTION RATIO

MERC      402     1972  40         Y          3344868        .5

                     CONCENTRATION DATA
  %CO     %CO2    %O2      NO    NOX   %THC    H2O    FUEL
                          PPM    PPM           GPS    LB/HP
  3.92     6.50   7.37    6.75    .00   5.85    32     2.48
  4.25     6.70   6.87    9.00    .00   5.75    32     2.48
  5.00     7.25   5.37   17.75    .00   4.50    32     5.78
  3.50     9.70   4.12   52.00    .00   3.20    30     7.43
  7.05     6.90   4.10   46.00  50.00   3.55    30    14.04
  4.60     9.75   4.12  115.00    .00   3.30    29    10.16
  3.70     6.55   7.25    8.00  11.75   5.70    29     2.48

             ENGINE DATA
 TIME  ENG     HP      TEMP      PITCH
       RPM           ENG  CARB
 1450   800   .10   73    68     13
 1505  1000   .71   74    68     13
 1513  2000  4.13   75    68     13
 1525  3000 10.95   80    68     13
 1535  4000 22.86   82    68     13
 1547  5000 40.00   85    68     13
 1602   800   .10   83    68     13

               CORRECTED CONCENTRATION DATA
   CO        CO2     O2        NO          NOX         F/A     A/F

  3.493     5.79    6.57      7.80         .00       .0762   13.1
  3.763     5.93    6.08      7.97         .00       .0781   12.8
  4.359     6.32    4.68     15.48         .00       .0782   12.8
  3.015     8.36    3.55     44.79         .00       .0757   13.2
  6.022     5.89    3.50     39.29       42.71       .0818   12.2
  3.956     7.53    3.54     98.91         .00       .0772   13.0
  3.303     5.85    6.47      7.14       10.49       .0747   13.4

                            MASS EMISSION DATA
EMIS  LB/HP     LB/HP-HR    KG/HP     KG/HP-HR LB/1000LB  G/TM     %FUEL UNB

CO   1.132E+00 1.13E+01 5.134E-01 5.13E+00 4.57E+02 1.04E-01 3.60E+01
     1.195E+00 1.67E+00 5.420E-01 7.59E-01 4.82E+02 8.81E-02 3.44E+01
     3.286E+00 7.96E-01 1.490E+00 3.61E-01 5.69E+02 1.21E-01 2.69E+01
     3.044E+00 2.78E-01 1.381E+00 1.26E-01 4.10E+02 7.48E-02 1.95E+01
     1.082E+01 4.73E-01 4.908E+00 2.15E-01 7.71E+02 1.99E-01 2.03E+01
     9.625E+00 2.41E-01 4.366E+00 1.09E-01 5.30E+02 1.42E-01 1.98E+01
     1.091E+00 1.09E+01 4.948E-01 4.95E+00 4.40E+02 1.00E-01 3.57E+01
CO2  2.948E+00 2.95E+01 1.337E+00 1.34E+01 1.19E+03 2.72E-01 3.60E+01
     2.959E+00 4.14E+00 1.342E+00 1.88E+00 1.19E+03 2.18E-01 3.44E+01
     7.484E+00 1.81E+00 3.395E+00 8.23E-01 1.29E+03 2.76E-01 2.69E+01
     1.325E+01 1.21E+00 6.011E+00 5.49E-01 1.78E+03 3.26E-01 1.95E+01
     1.663E+01 7.28E-01 7.545E+00 3.30E-01 1.19E+03 3.06E-01 2.03E+01
     2.876E+01 7.19E-01 1.304E+01 3.26E-01 1.58E+03 4.24E-01 1.98E+01
     3.033E+00 3.03E+01 1.376E+00 1.38E+01 1.22E+03 2.79E-01 3.57E+01
NO   4.147E-04 4.15E-03 1.881E-04 1.88E-03 1.67E-01 3.82E-05 3.60E+01
     4.153E-04 5.82E-04 1.884E-04 2.64E-04 1.68E-01 3.06E-05 3.44E+01
     1.915E-03 4.64E-04 8.685E-04 2.10E-04 3.31E-01 7.05E-05 2.69E+01
     7.424E-03 6.78E-04 3.367E-03 3.08E-04 9.99E-01 1.82E-04 1.95E+01
     1.159E-02 5.07E-04 5.257E-03 2.30E-04 8.26E-01 2.14E-04 2.03E+01
     3.950E-02 9.87E-04 1.792E-02 4.48E-04 2.17E+00 5.82E-04 1.98E+01
     3.871E-04 3.87E-03 1.756E-04 1.76E-03 1.56E-01 3.57E-05 3.57E+01
NOX  0.000E-01 0.00E-01 0.000E-01 0.00E-01 0.00E-01 0.00E-01 3.60E+01
     0.000E-01 0.00E-01 0.000E-01 0.00E-01 0.00E-01 0.00E-01 3.44E+01
     0.000E-01 0.00E-01 0.000E-01 0.00E-01 0.00E-01 0.00E-01 2.69E+01
     0.000E-01 0.00E-01 0.000E-01 0.00E-01 0.00E-01 0.00E-01 1.95E+01
     1.260E-02 5.51E-04 5.714E-03 2.50E-04 8.97E-01 2.32E-04 2.03E+01
     0.000E-01 0.00E-01 0.000E-01 0.00E-01 0.00E-01 0.00E-01 1.98E+01
     5.686E-04 5.69E-03 2.579E-04 2.58E-03 2.30E-01 5.24E-05 3.57E+01
THC  9.575E-01 9.57E+00 4.343E-01 4.34E+00 3.87E+02 8.82E-02 3.60E+01
     9.221E-01 1.29E+00 4.183E-01 5.86E-01 3.72E+02 6.80E-02 3.44E+01
     1.713E+00 4.15E-01 7.771E-01 1.88E-01 2.96E+02 6.31E-02 2.69E+01
     1.632E+00 1.49E-01 7.402E-01 6.76E-02 2.20E+02 4.01E-02 1.95E+01
     3.221E+00 1.41E-01 1.461E+00 6.39E-02 2.30E+02 5.93E-02 2.03E+01
     4.055E+00 1.01E-01 1.839E+00 4.60E-02 2.23E+02 5.98E-02 1.99E+01
     9.508E-01 9.51E+00 4.313E-01 4.31E+00 3.84E+02 8.76E-02 3.57E+01

RUN AGAIN (Y OR N)
? N
END

-LOG OUT

CPU TIME: 55 SECS.
TERMINAL TIME: 0:34:33
```

2.9.2 Water/Exhaust Mixing Data Reduction

The data reduction for the water/exhaust mixing was performed manually. Following the procedures adopted in the SWRI study (Reference 1), the mass emissions were calculated on the basis of a nitrogen balance. This assumes that the total nitrogen mass flow is conserved through the water/exhaust mixing system. The nitrogen concentrations before and after water contact are calculable by subtracting the mole percentages of the known exhaust constituents from 100 percent. This approach directs that the ratios of the nitrogen concentration before and after water contact are equal to the ratios of the total exhaust on a mole basis before and after contact. The percent loss of each constituent (X_L) on a mass basis can be calculated by:

$$\% X_L = 100 \frac{X_B - \frac{(N_2B)(X_A)}{(N_2A)}}{X_B} \quad (5)$$

where: X_B = X concentration before

X_A = X concentration after

N_2B = N_2 concentration before

N_2A = N_2 concentration after.

This loss when subtracted from 100 percent and multiplied by the total mass of constituent X emitted (from carbon balance) will give the total mass emitted to the air after water contact. That is, $(100\% - \% X_L) M_{X_B} = M_{X_A}$ where X = CO, CO_2, O_2, NO_x, or THC. The gases can be corrected for pressure by using Henry's law: The mass of a soluble gas that dissolves in a liquid at a given temperature is proportional to the partial pressure of that gas (where molecular dissociation is not involved).

3. RESULTS

This section will summarize the results and present the data on an engine-by-engine basis.

3.1 1959 JOHNSON, 50 HP

This engine was used as the preliminary "work horse" to check out and set up the equipment and instrumentation. No data was available on the total engine hours or the hours since last tune-up. The engine had a well-used appearance and evidently had had one bank of cylinder heads replaced recently, indicating a major repair effort. Late in the test program, an overheating problem was encountered because of a faulty water pump. It was difficult to maintain the cylinder head temperature below the recommended 135° F, especially at high loads. However, temperatures up to 150° F were tolerated with no apparent change in emissions or fuel economy.

It was difficult to hold the set speed with this engine at 2000 rpm. It was also noted that this point gave high emission rates. This was later attributed to improper magneto-to-carburetor linkage adjustment. In the as-received condition the maximum horsepower that could be attained at the rated speed was 44 hp.

Figures 28 through 33 give the average mass emission rates, percentage fuel unburned, and the BSFC of this engine before and after tune-up. The higher levels of CO_2 and NO_x indicated that the engine was performing more satisfactorily after tune-up. Also, the engine was now capable of 50 hp at its rated speed. Although there was no significant change in the levels of CO and THC (in fact at some speeds they increased), the percentage of fuel passing through the engine as unburned hydrocarbons decreased due to the improvement in fuel economy as can be noted in Figure 33. The improvement in fuel economy varied from approximately 30 percent at 2000 rpm to a few percent at 4000 rpm.

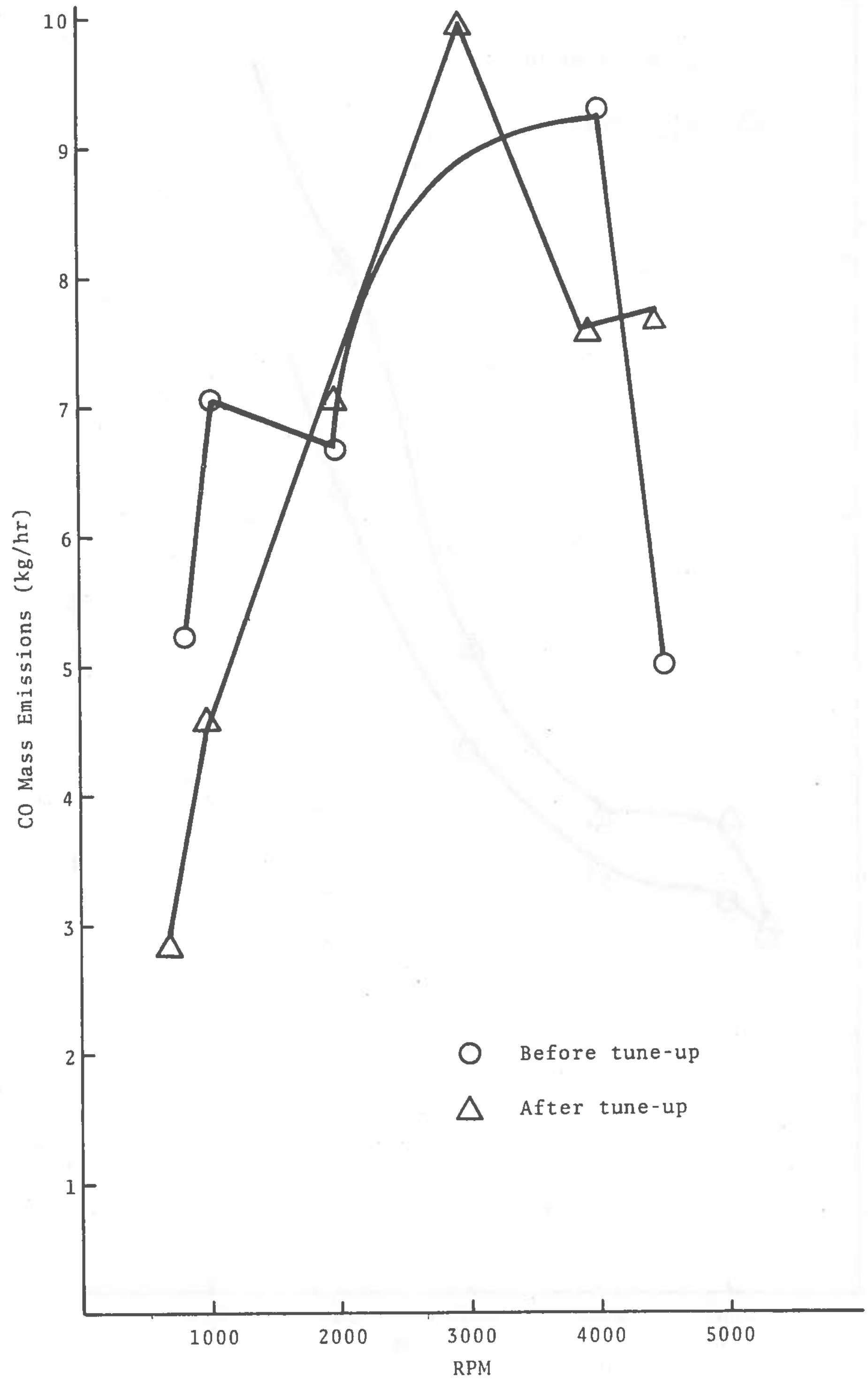


Figure 28. Average CO Emissions Before and After Tune-up (1959 Johnson, 50 HP)

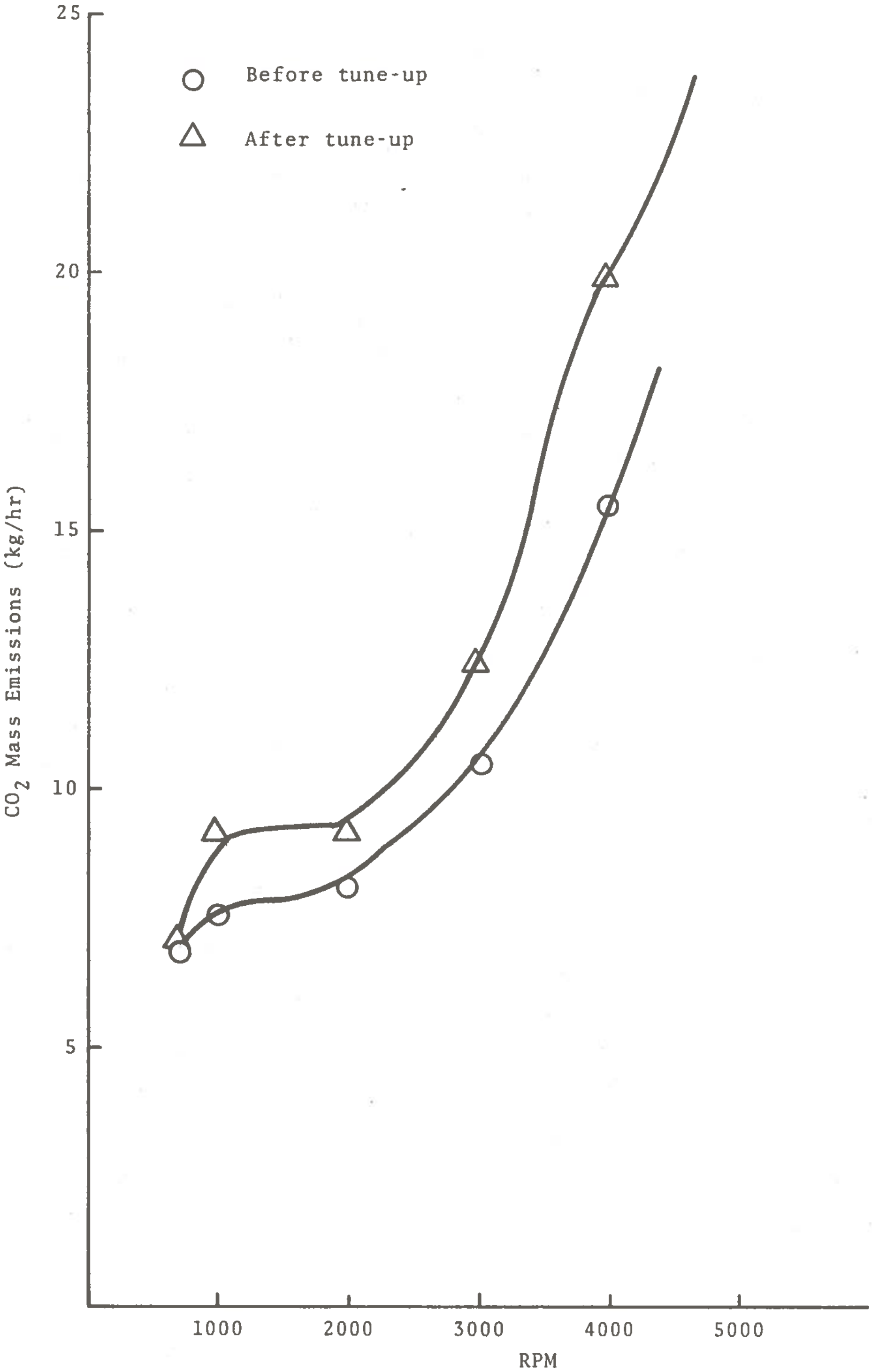


Figure 29. Average CO_2 Emissions Before and After Tune-up (1959 Johnson, 50 HP)

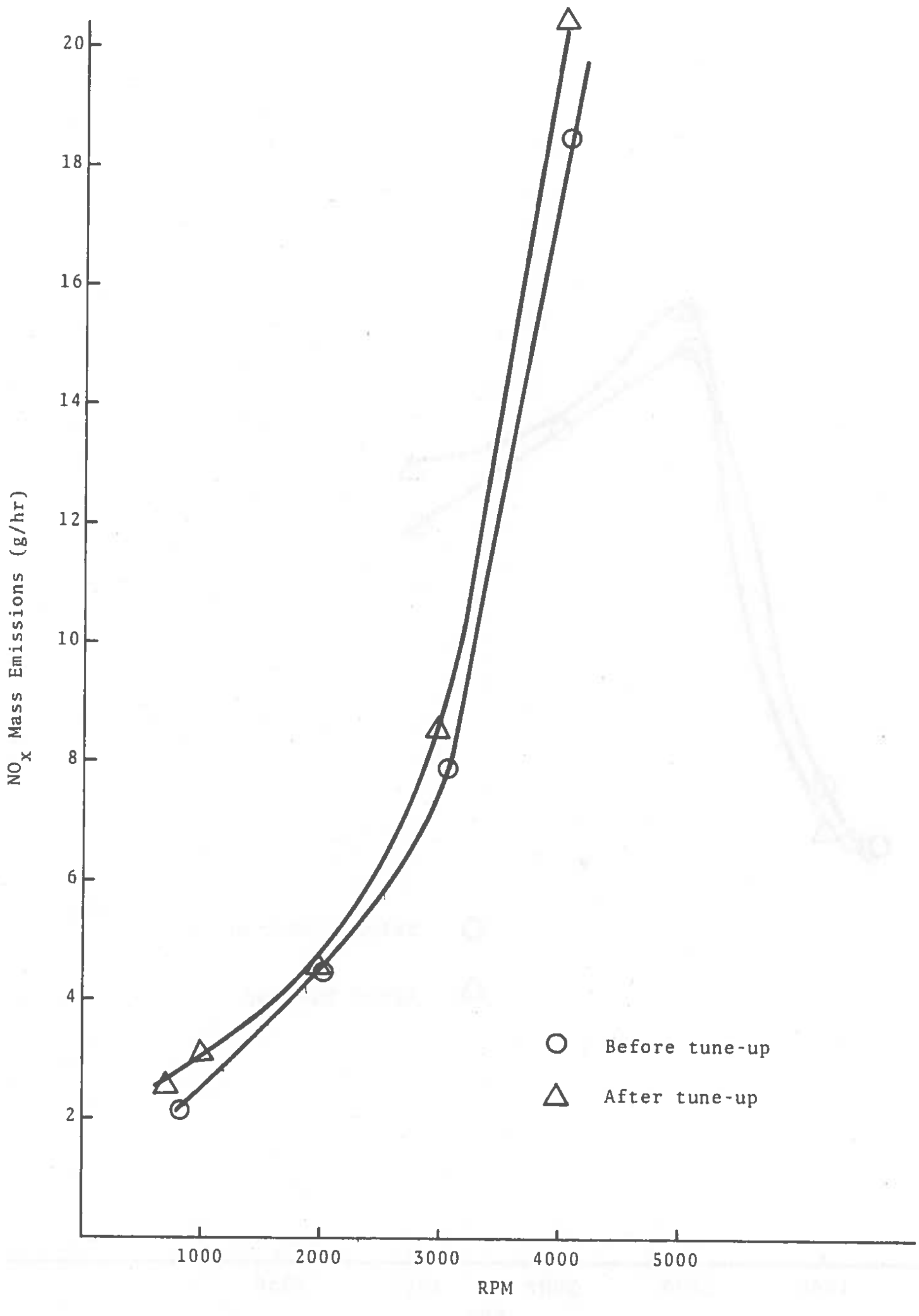


Figure 30. Average NO_x Emissions Before and After Tune-up (1959 Johnson, 50 HP)

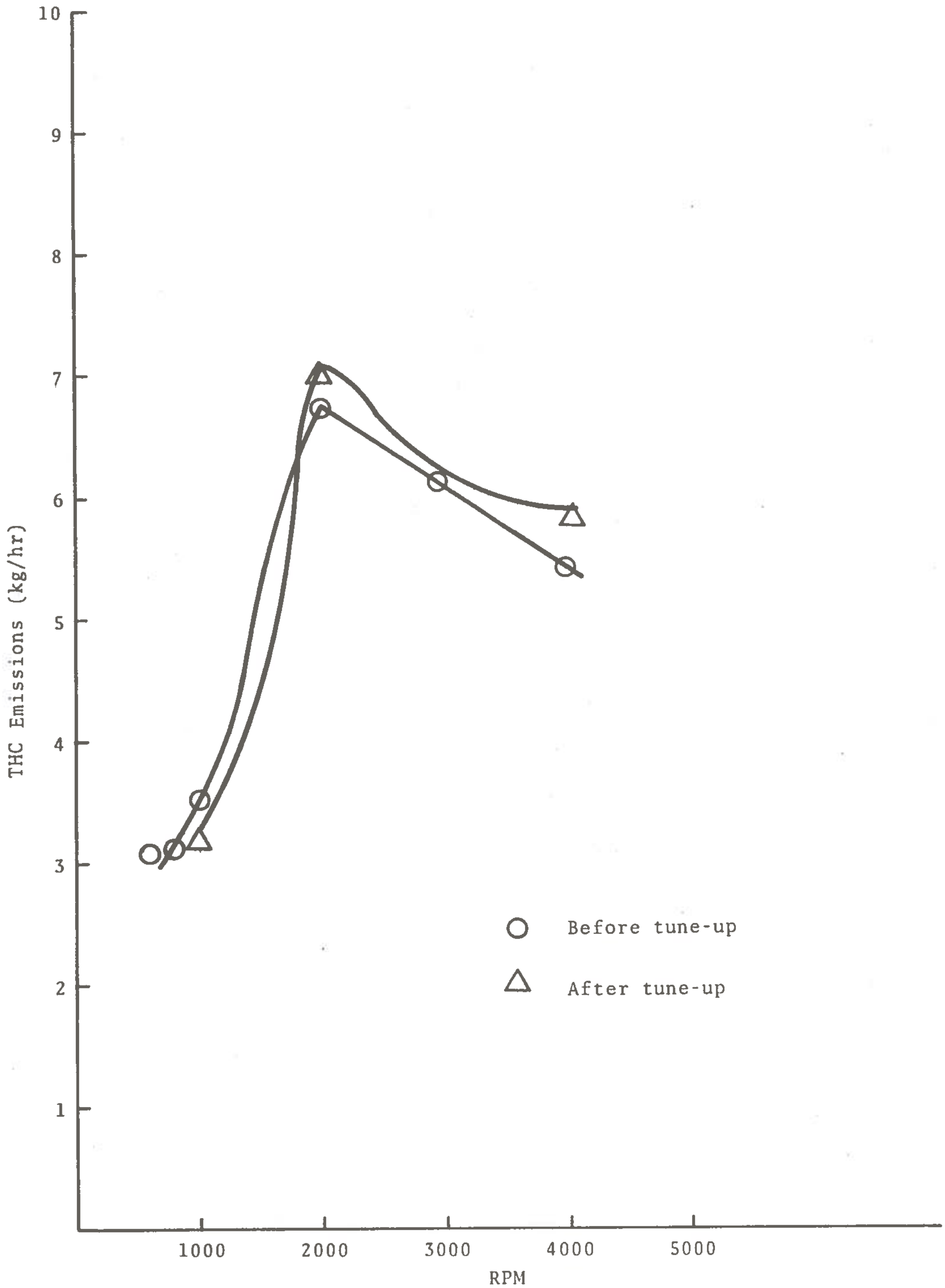


Figure 31. Average THC Mass Emissions Before and After Tune-up (1959 Johnson, 50 HP)

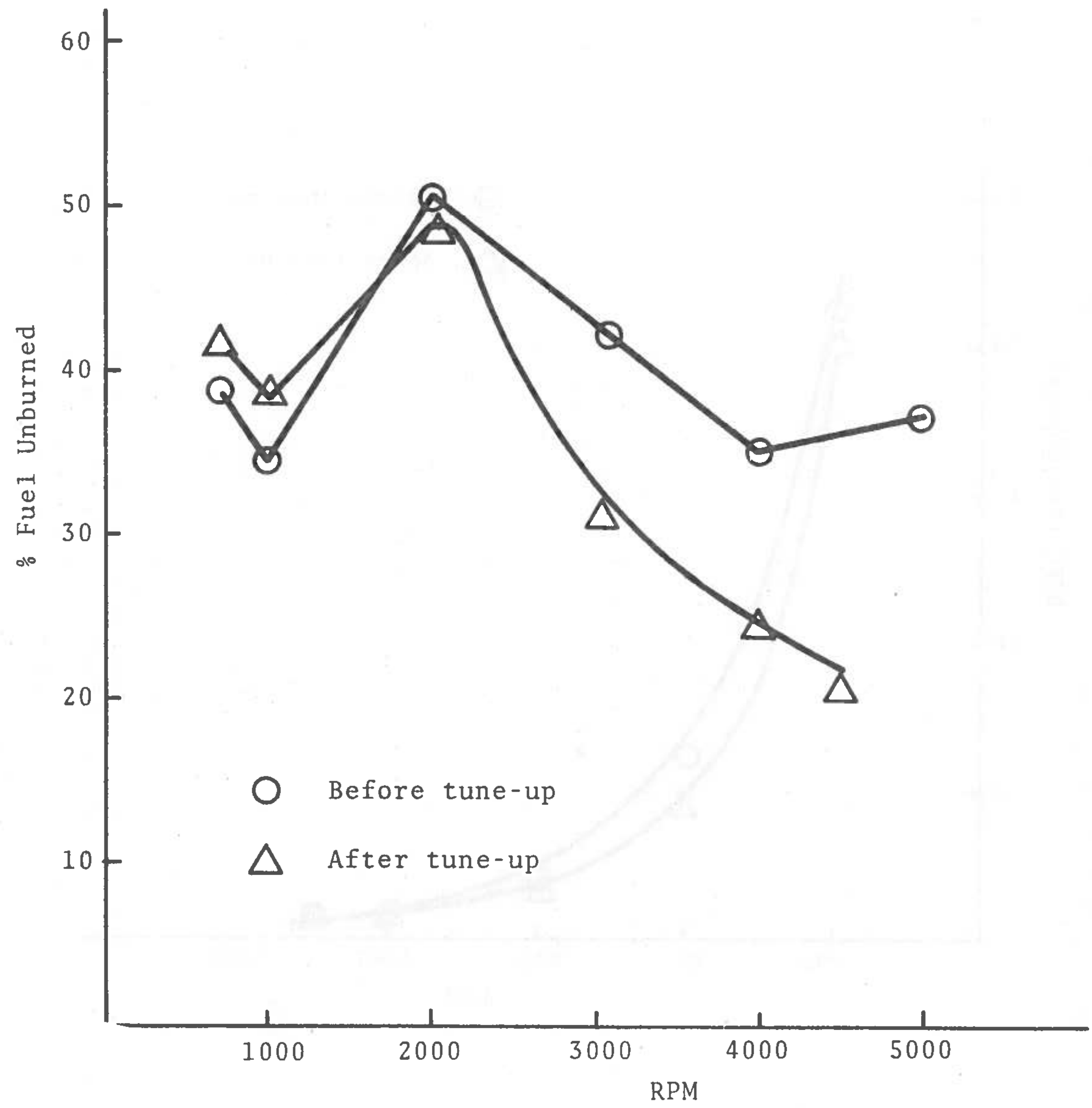


Figure 32. Average Percent Fuel Unburned Before and After Tune-up (1959 Johnson, 50 HP)

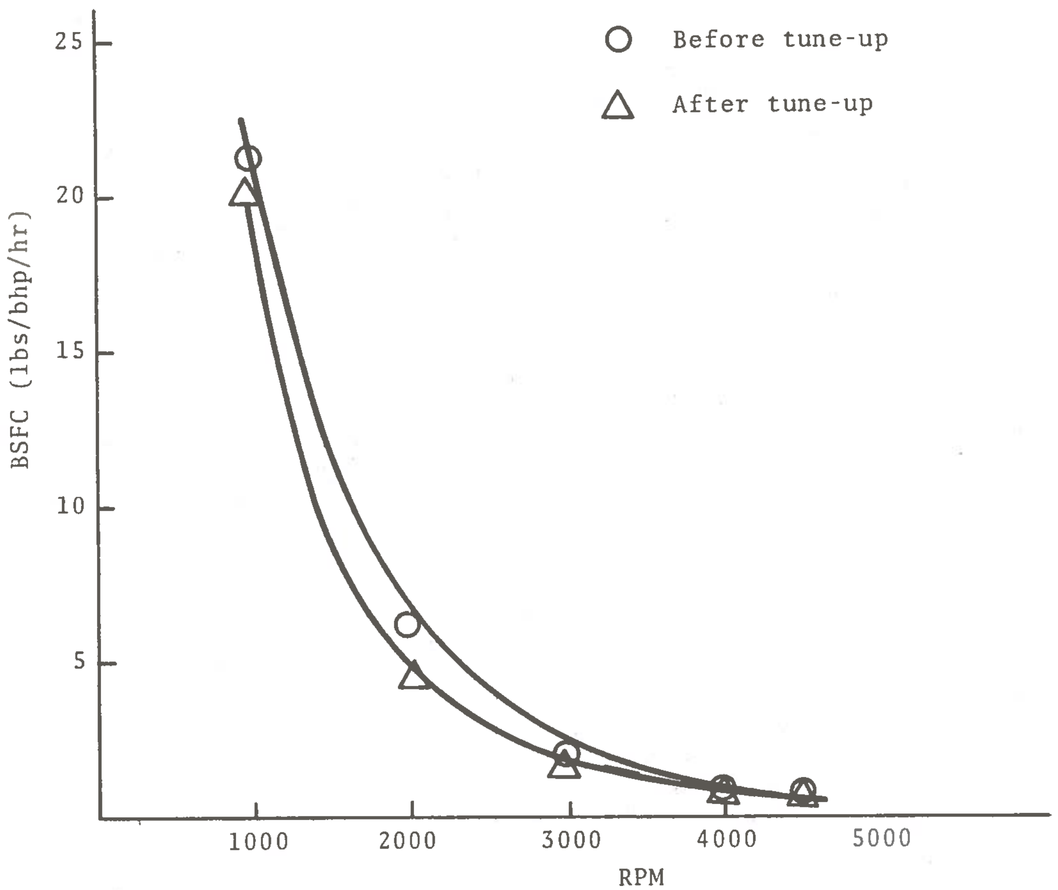


Figure 33. Brake Specific Fuel Consumption Before and After Tune-up (1959 Johnson, 50 HP)

3.2 1964 MERCURY, 65 HP

This engine appeared to have had limited use for an engine of its age. The spark plugs had been changed at the end of the previous boating season. The engine started and ran reasonably well, with some roughness noted at low speeds. This engine, however, would not hold the speed and load at 3000 rpm and it was usually necessary to cut back the throttle to approximately 2600 rpm to obtain stable operation.

After tune-up, the engine ran smoothly at all speeds (the original ignition points were in poor condition) and rated horsepower and speed were easily obtained. Figures 34 through 39 show the average mass emission rates, percent fuel burned, and the BSFC for this engine before and after tune-up. A considerable improvement in emissions and fuel economy were noted.

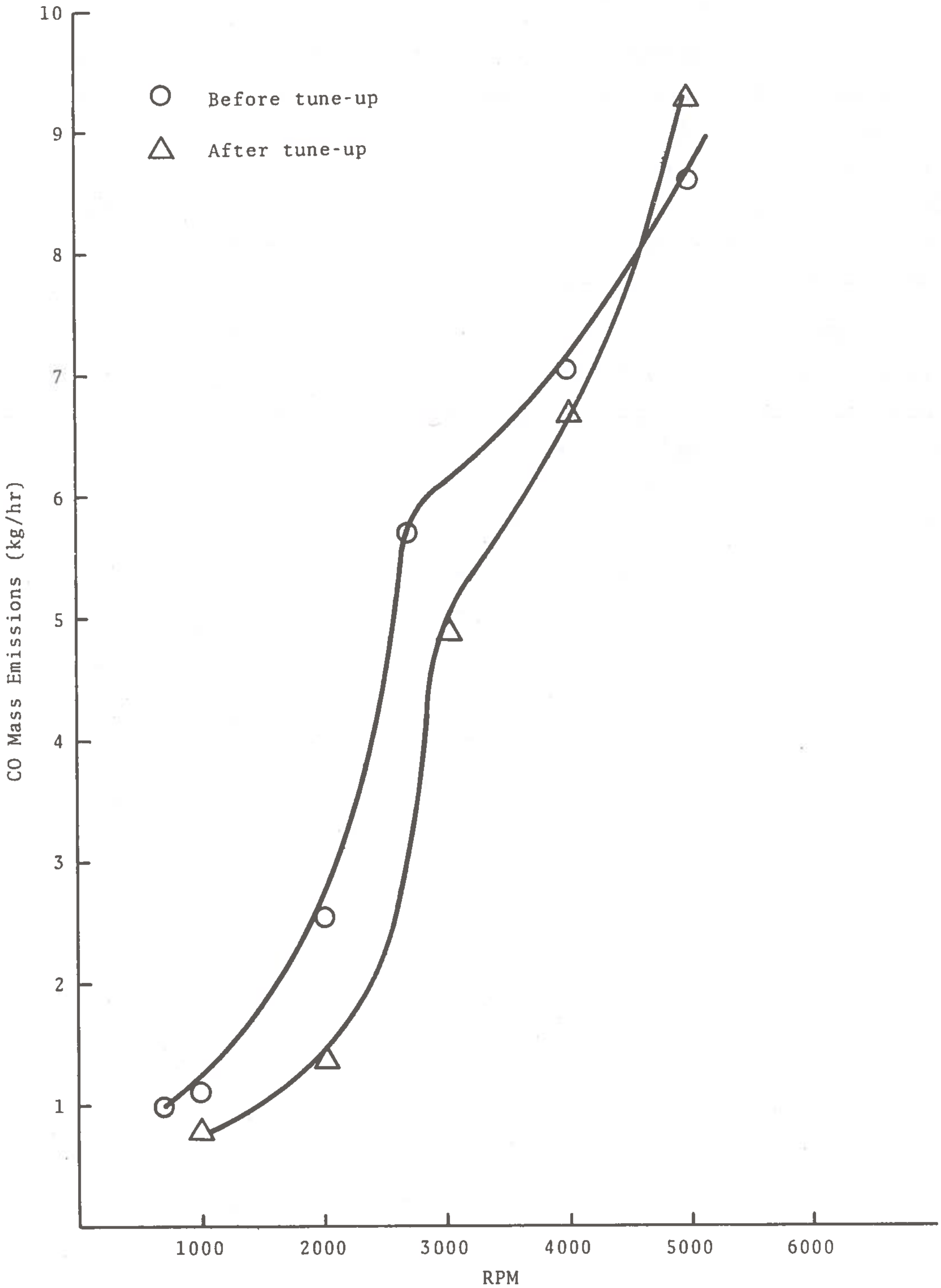


Figure 34. Average CO Emissions Before and After Tune-up (1964 Mercury, 65 HP)

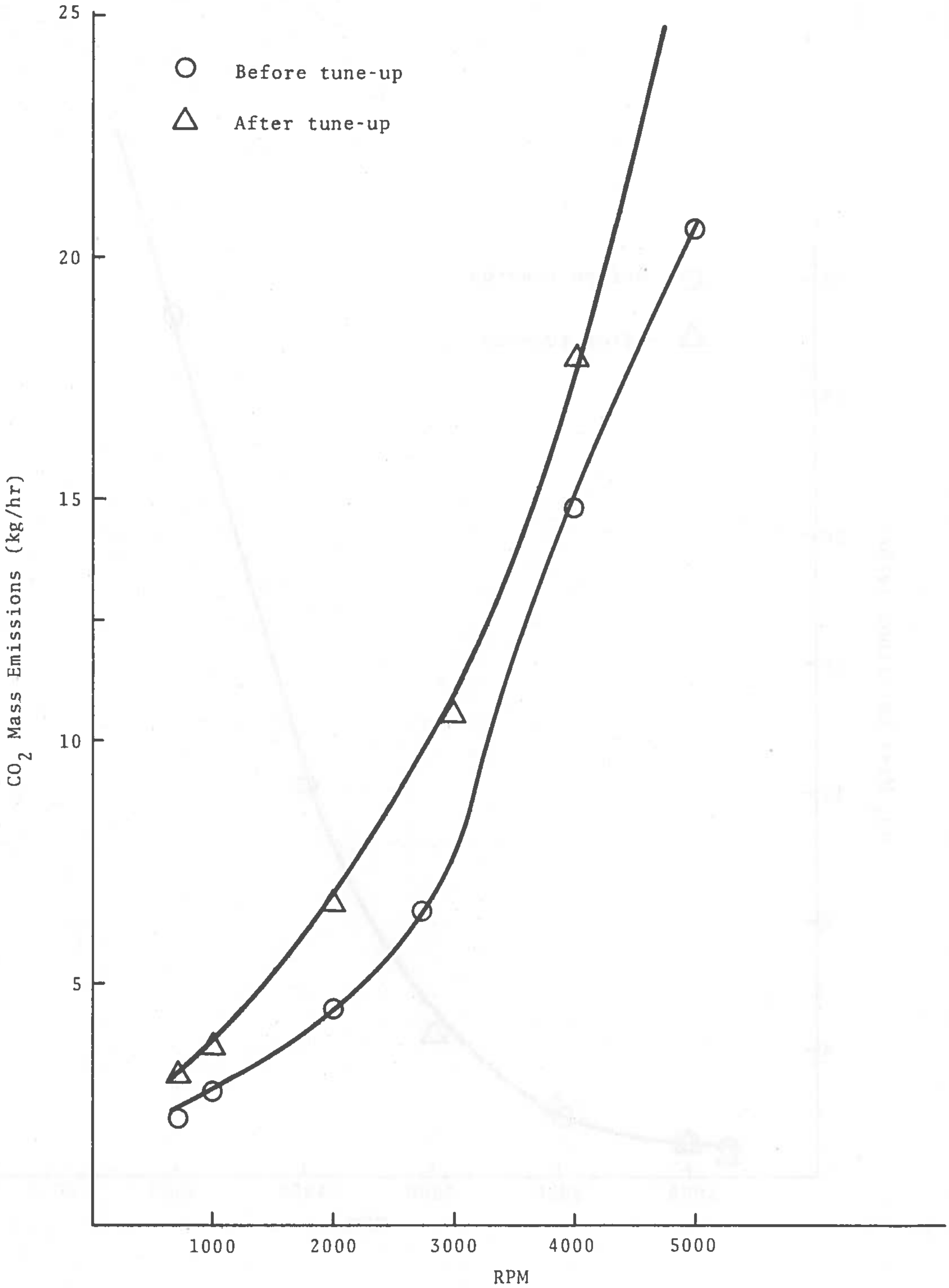


Figure 35. Average CO_2 Emissions Before and After Tune-up (1964 Mercury, 65 HP)

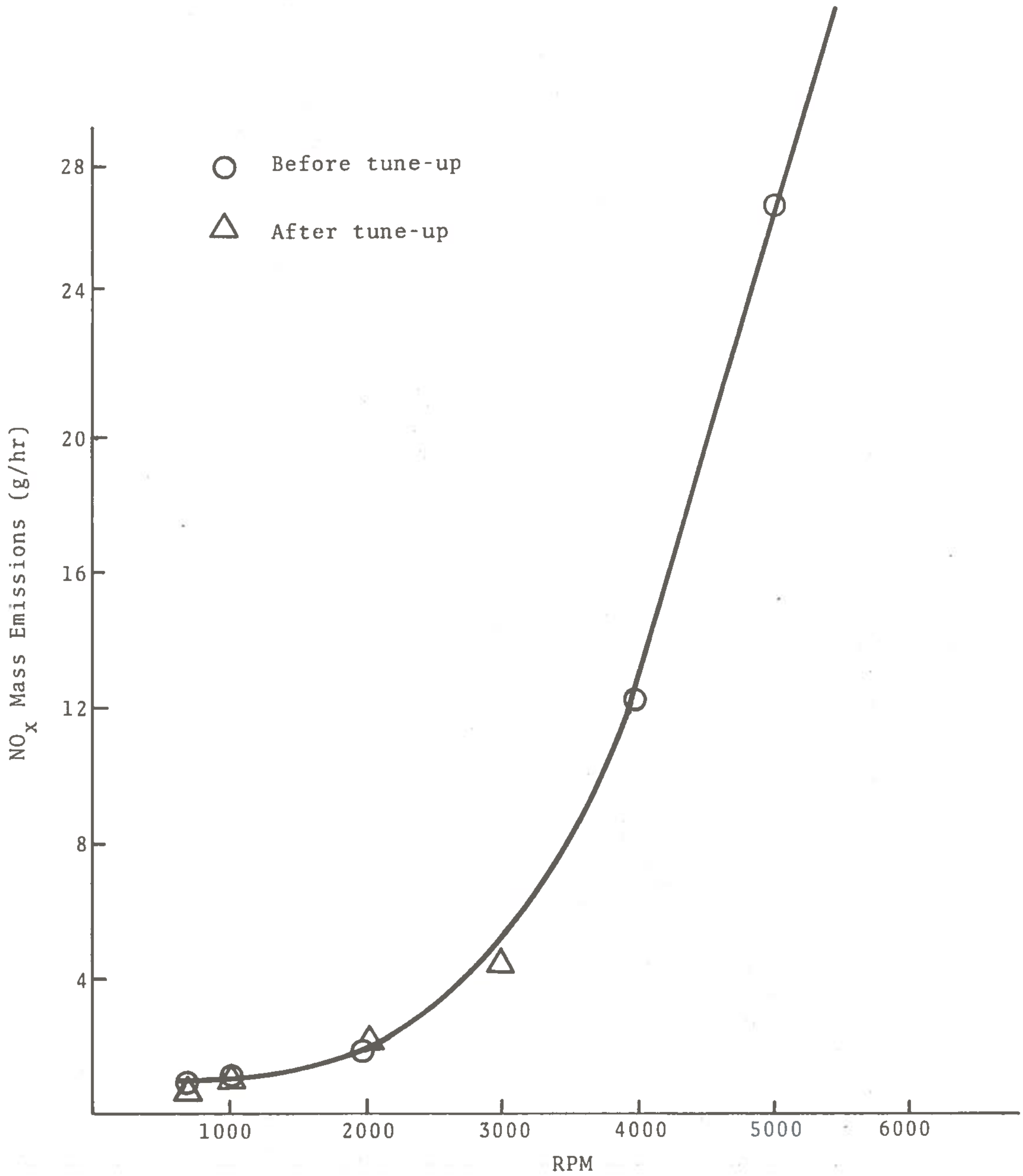


Figure 36. Average NO_x Emissions Before and After Tune-up (1964 Mercury, 65 HP)

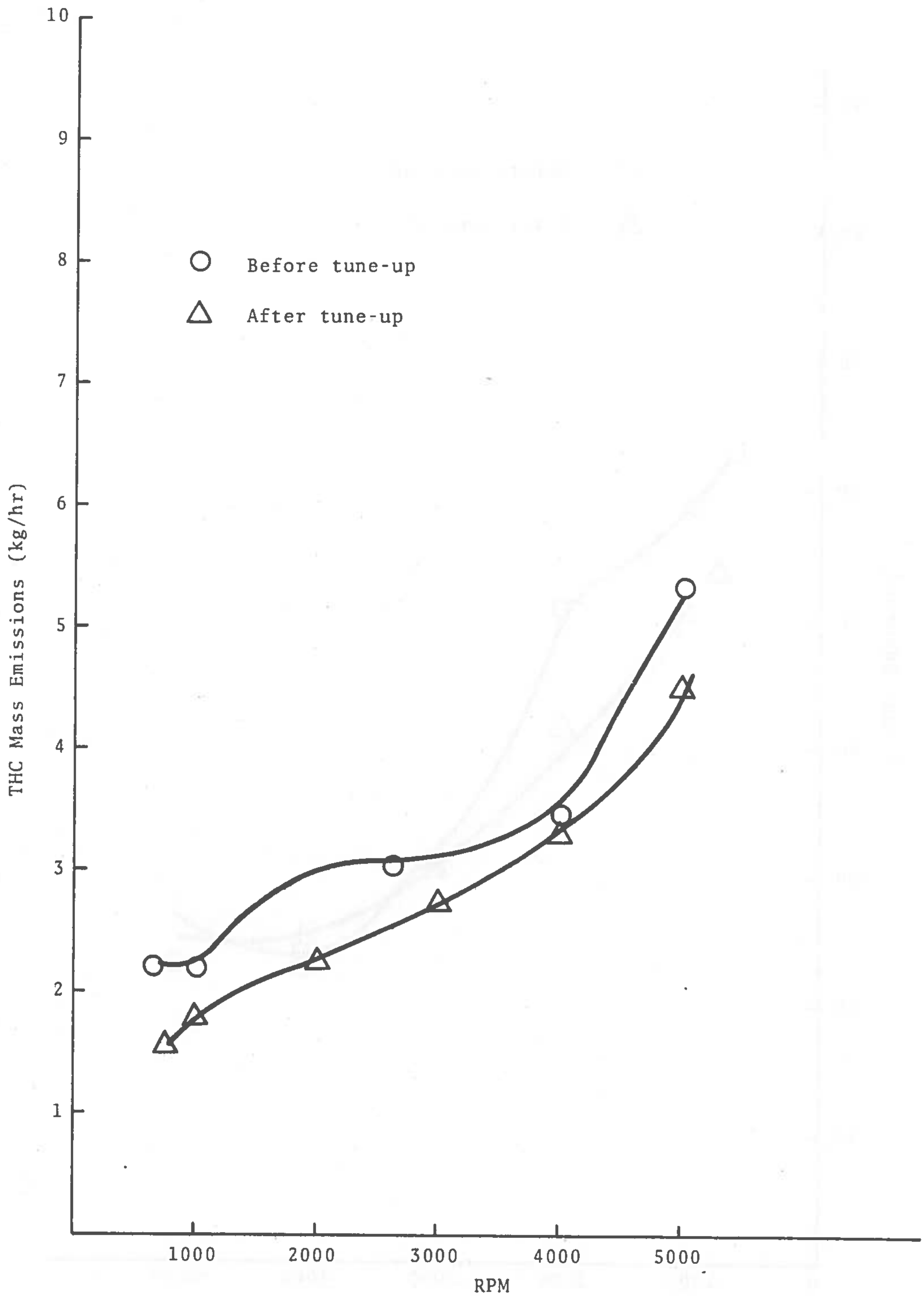


Figure 37. Average THC Mass Emissions Before and After Tune-up (1964 Mercury, 65 HP)

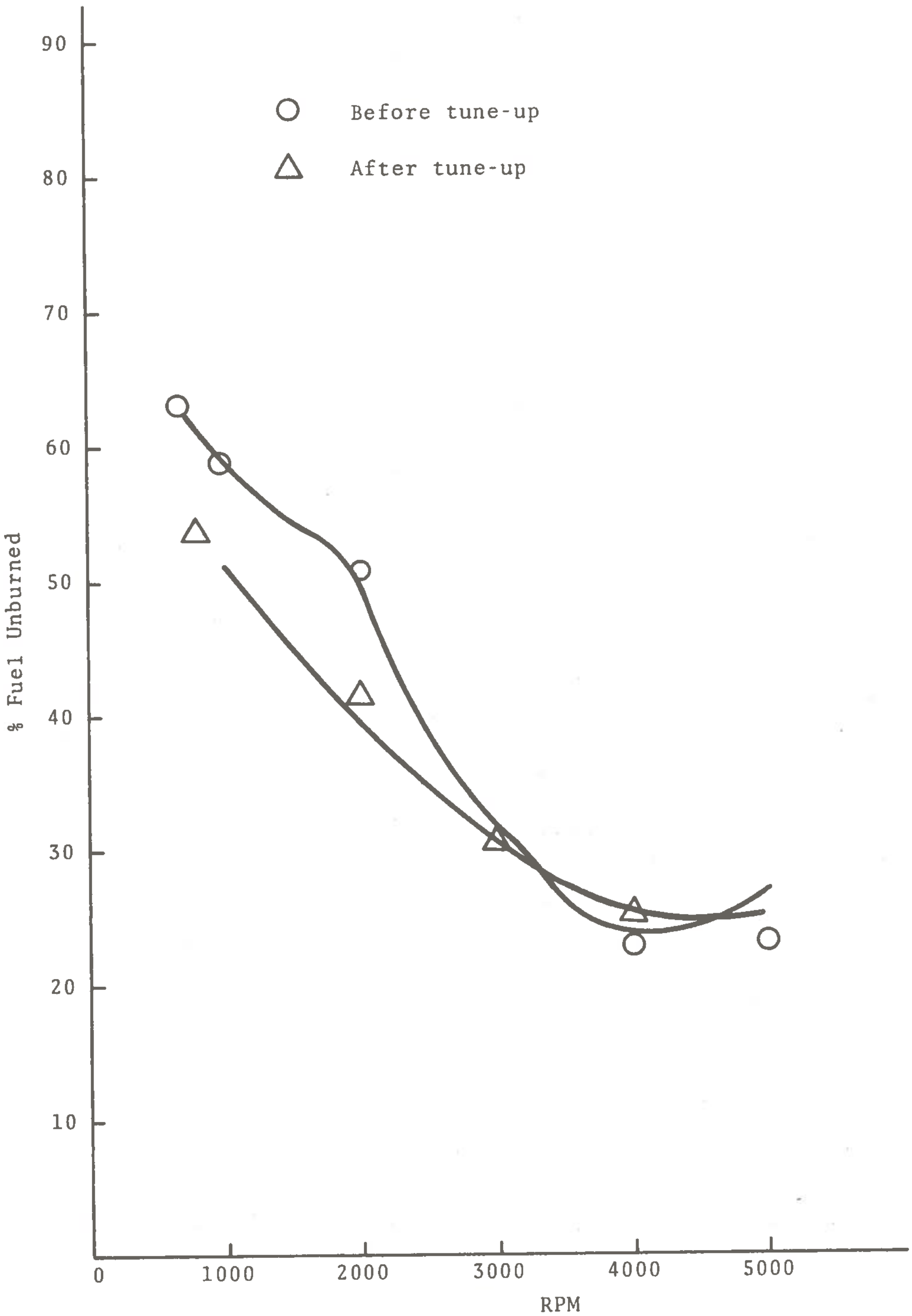


Figure 38. Average Percent Fuel Unburned Before and After Tune-up (1964 Mercury, 65 HP)

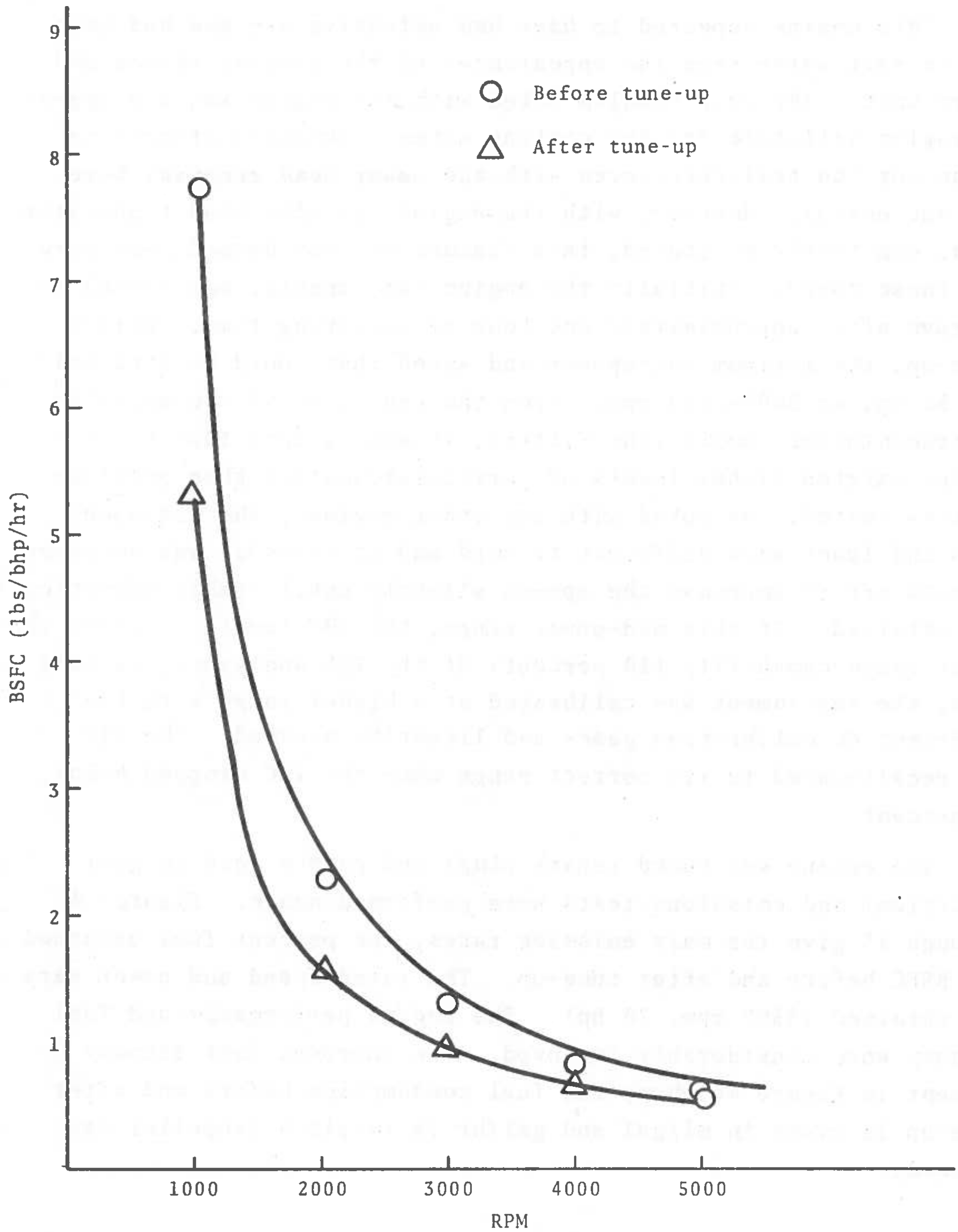


Figure 39. Brake Specific Fuel Consumption Before and After Tune-up (1964 Mercury, 65 HP)

3.3 1962 MERCURY, 70 HP

This engine appeared to have had extensive use and had been run in salt water from the appearances of the cooling system and lower unit. The only problem noted with the engine was a plugged-up engine tell-tale for the cooling water. Repeated efforts to clean out the tell-tale (even with the power head removed) were not successful. However, with the engine cylinder head temperature being constantly monitored, this feature was not deemed necessary for these tests. Initially the engine ran roughly, but seemed to improve after approximately one hour of operating time. Before tune-up, the maximum horsepower and speed that could be attained was 56 hp, at 5000-5100 rpm. From the condition of the emission instrumentation sample line filters, it was evident that this engine emitted higher levels of particulate matter than previous engines tested. As noted with the other engines, the mid-speed rpm's and loads were difficult to hold and at times it was necessary to back off or increase the speeds slightly until stable operation was attained. At this mid-power range, the THC levels exceeded the upper range capability (10 percent) of the FID analyzer. In this case, the instrument was calibrated at a higher range with two different HC calibration gases and linearity assumed. The FID was recalibrated to its correct range when the THC dropped below 10 percent.

The engine was tuned (spark plugs and points were in poor condition) and emissions tests were performed again. Figures 40 through 45 give the mass emission rates, the percent fuel unburned and BSFC before and after tune-up. The rated speed and power were now obtained (5500 rpm, 70 hp). The engine performance and fuel economy were considerably improved. The improved fuel economy is evident in Figure 46 where the fuel consumption before and after tune-up is given in mi/gal and gal/hr (a 14-pitch propeller was assumed).

3.4 1974 EVINRUDE, 40 HP

The 1974 Evinrude 40 hp was a new engine on loan from the U.S. Coast Guard. The engine was initially "run-in" on the dynamometer test stand for approximately 6 hours at varying speeds and loads prior to emission measurements. The engine seemed to run rough at low speeds and loads (up to 2000 rpm) but smoothed out at higher speeds. A check of engine ignition, carburetion and timing indicated that all was in order. This engine has an external lean/rich carburetor adjustment and emissions tests were run with lean mixtures, rich mixtures and the adjustment set at mid-point (recommended for normal operation). Figures 47 through 50 give the average mass emission rates, percentage of fuel unburned, and the BSFC for this engine at mid-carburetor setting. Since this engine was new, no tune-up was performed. The results are plotted in Figures 51 through 55 of the mass emission rates for rich and lean settings for CO, CO_2, NO_x, THC, and the percentage fuel unburned.

The run-to-run variations in the emission rates of the engines tested appeared to be excessive. To examine these fluctuations more closely, statistical analysis was performed on the test results. Table 4 gives the mean, standard deviation, standard error, maximum, minimum, and range of the mass emission rates for the four runs performed on the Evinrude engine at mid-carburetor setting.

Table 5 gives the results of the two-sided 90 percent confidence level test.

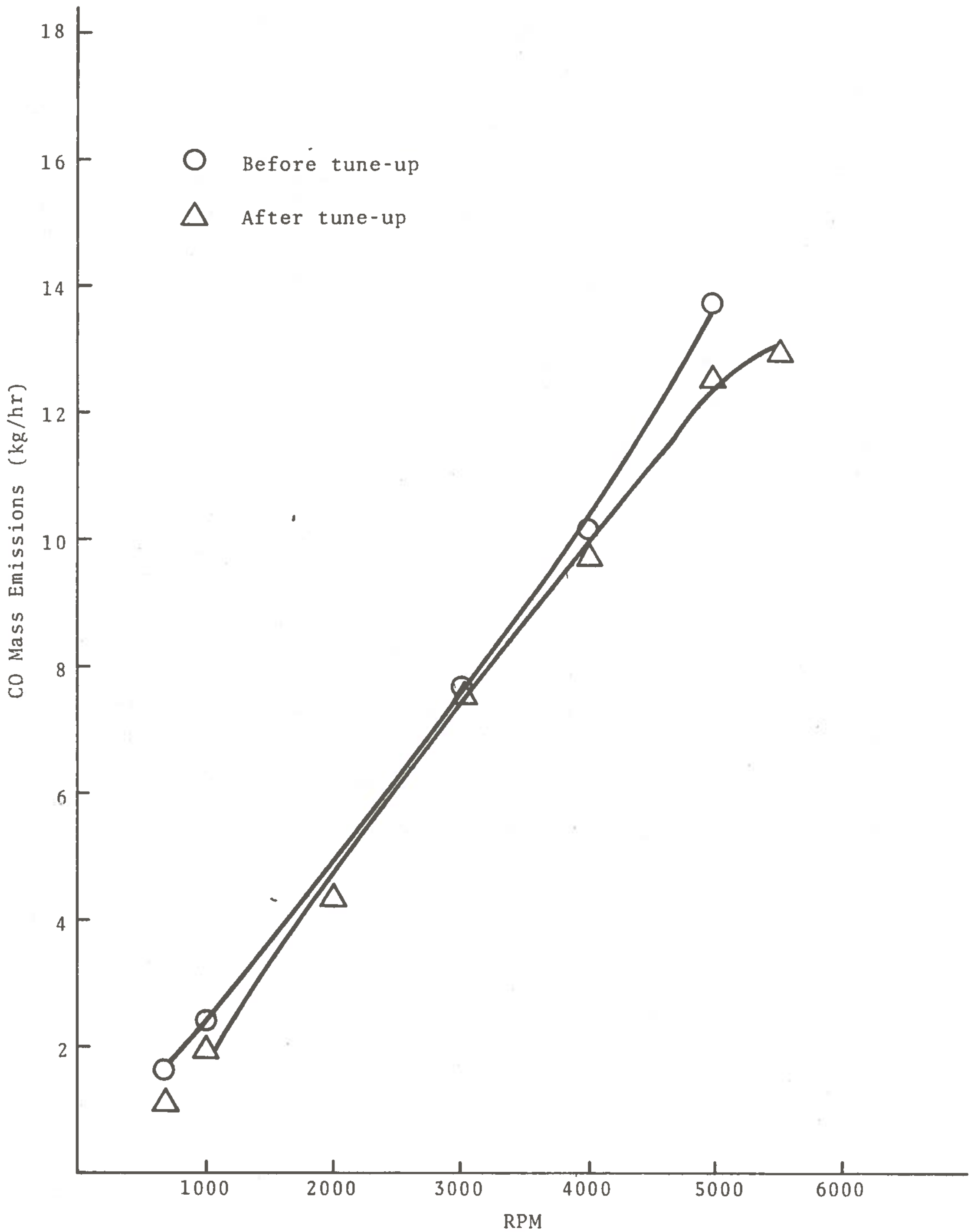


Figure 40. Average CO Emission Rates Before and After Tune-up (1962 Mercury, 70 HP)

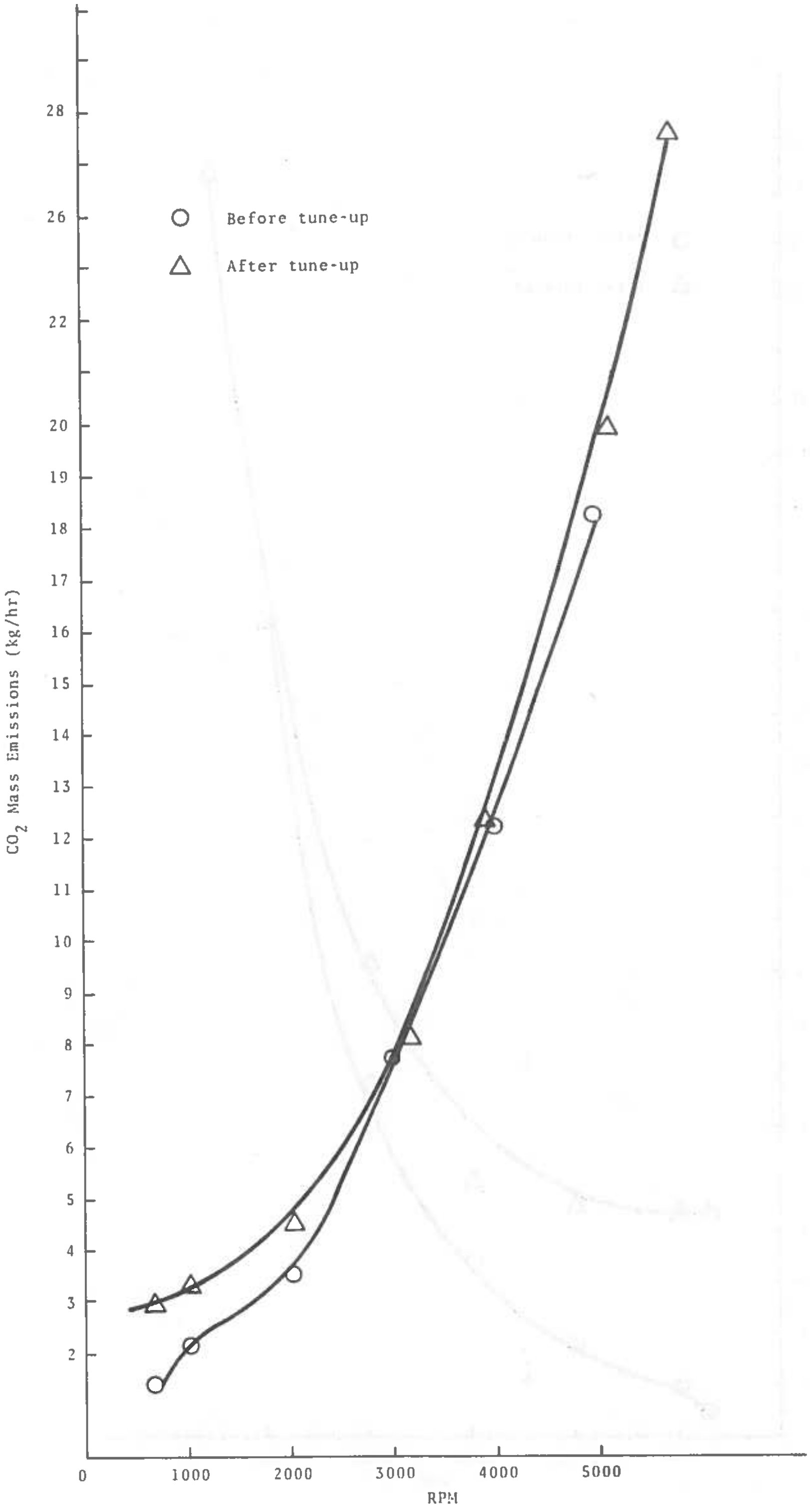


Figure 41. Average CO_2 Emissions Before and After Tune-up (1962 Mercury, 70 HP)

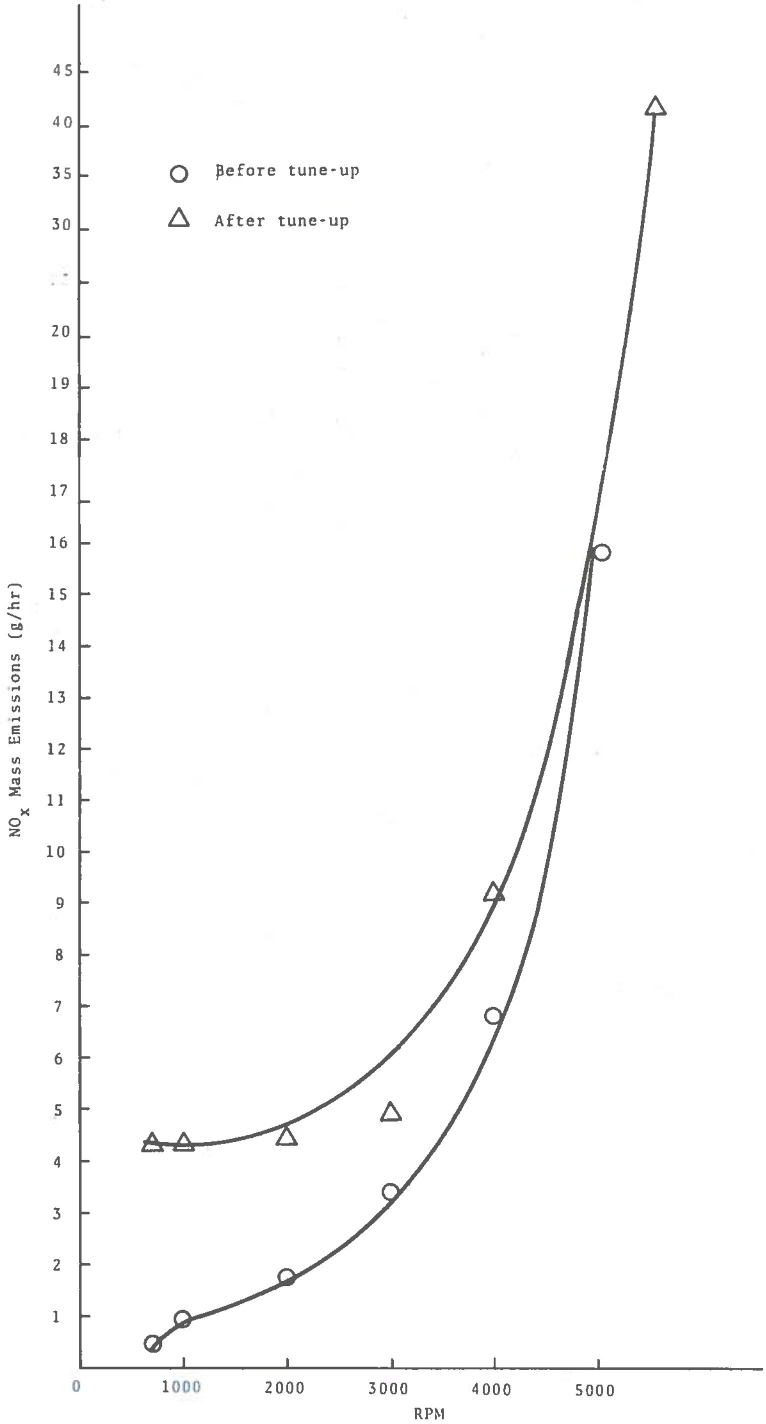


Figure 42. Average NO_x Emissions Before and After Tune-up (1962 Mercury, 70 HP)

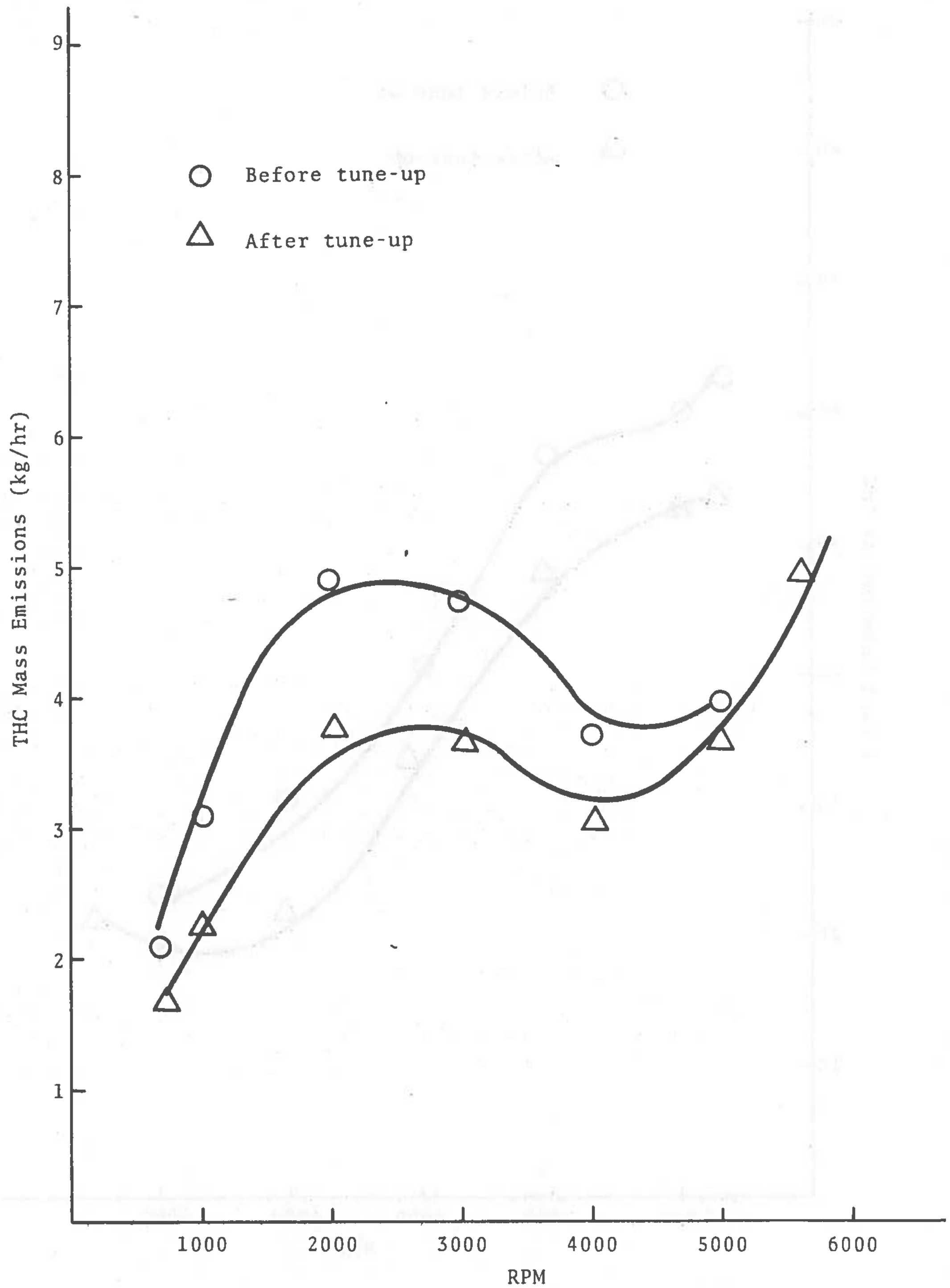


Figure 43. Average THC Mass Emissions Before and After Tune-up (1962 Mercury, 70 HP)

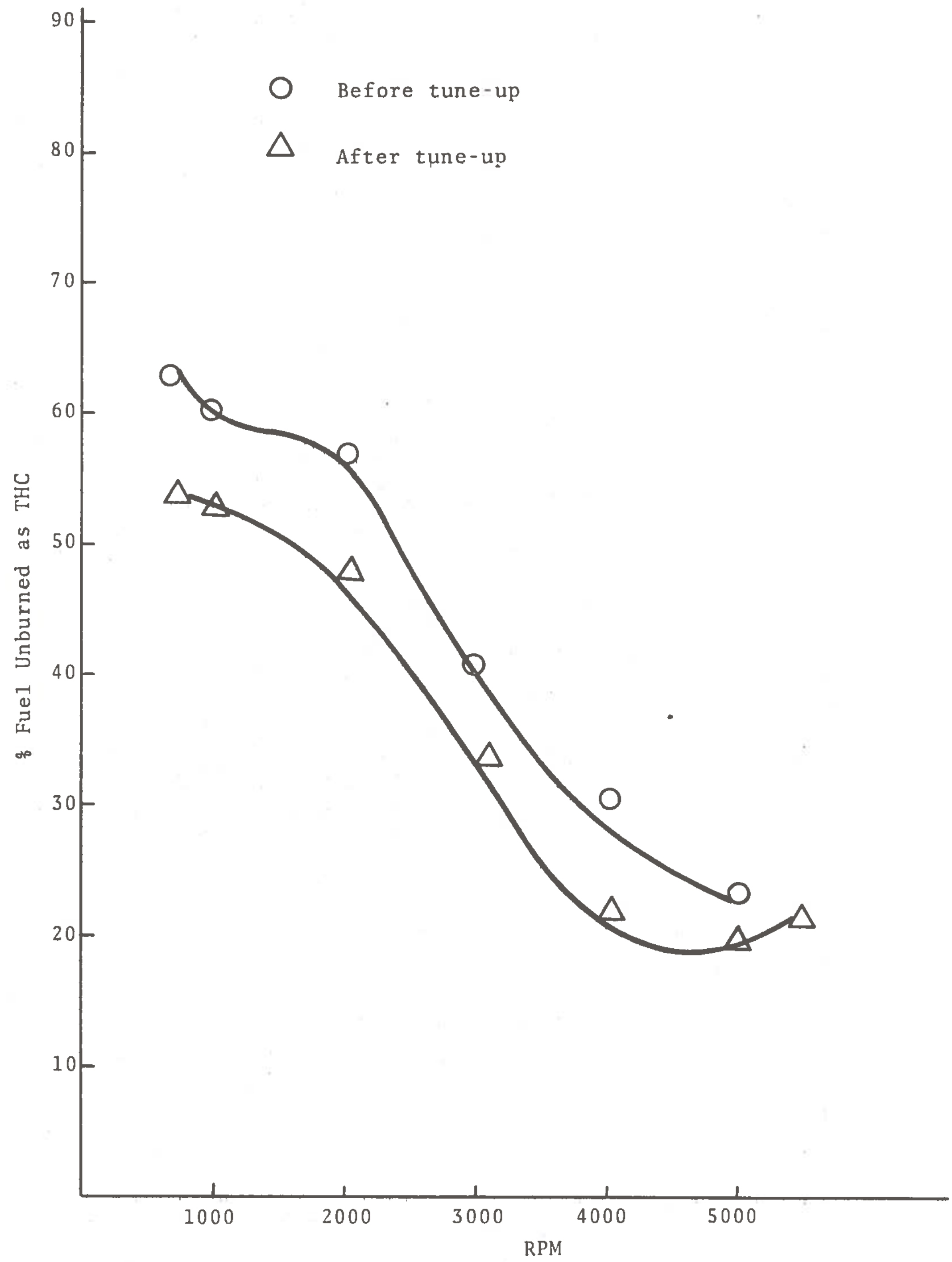


Figure 44. Average Percent Fuel Unburned Before and After Tune-up (1962 Mercury, 70 HP)

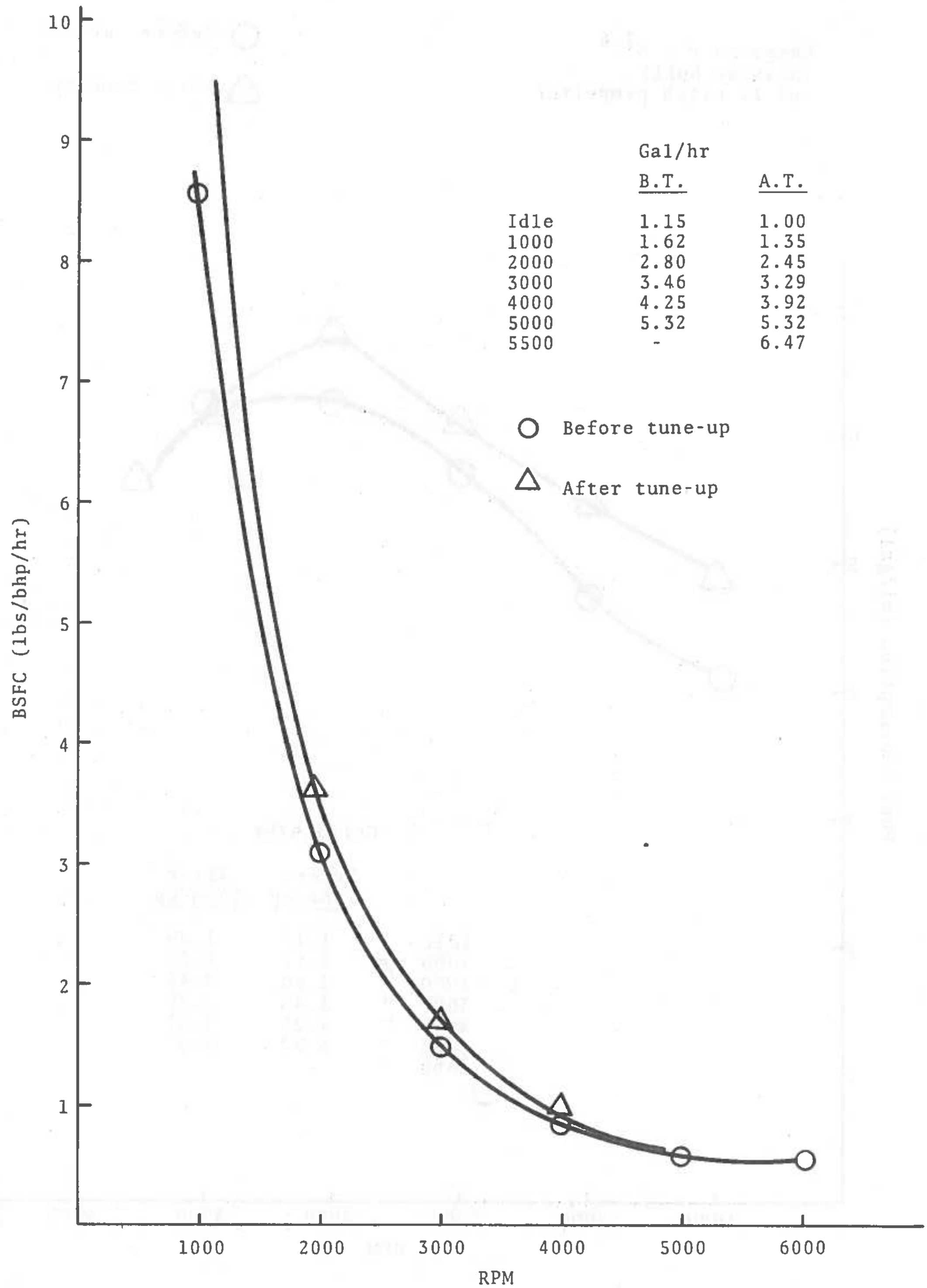
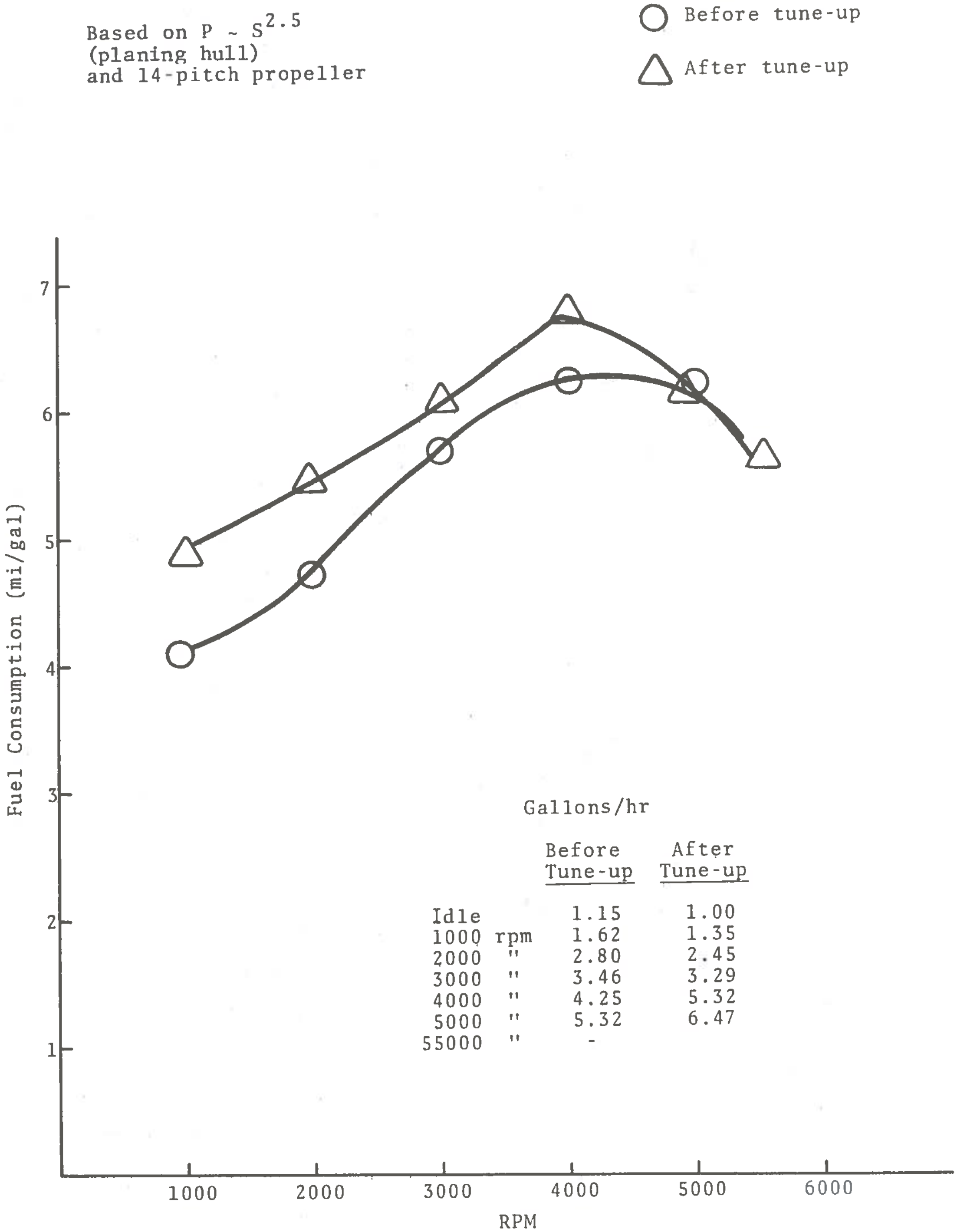


Figure 45. Brake Specific Fuel Consumption Before and After Tune-up (1962 Mercury, 70 HP)



	Before Tune-up	After Tune-up
Idle	1.15	1.00
1000 rpm	1.62	1.35
2000 "	2.80	2.45
3000 "	3.46	3.29
4000 "	4.25	5.32
5000 "	5.32	6.47
55000 "	-	

Figure 46. Effect of Tune-up on Fuel Consumption (1962 Mercury, 70 HP)

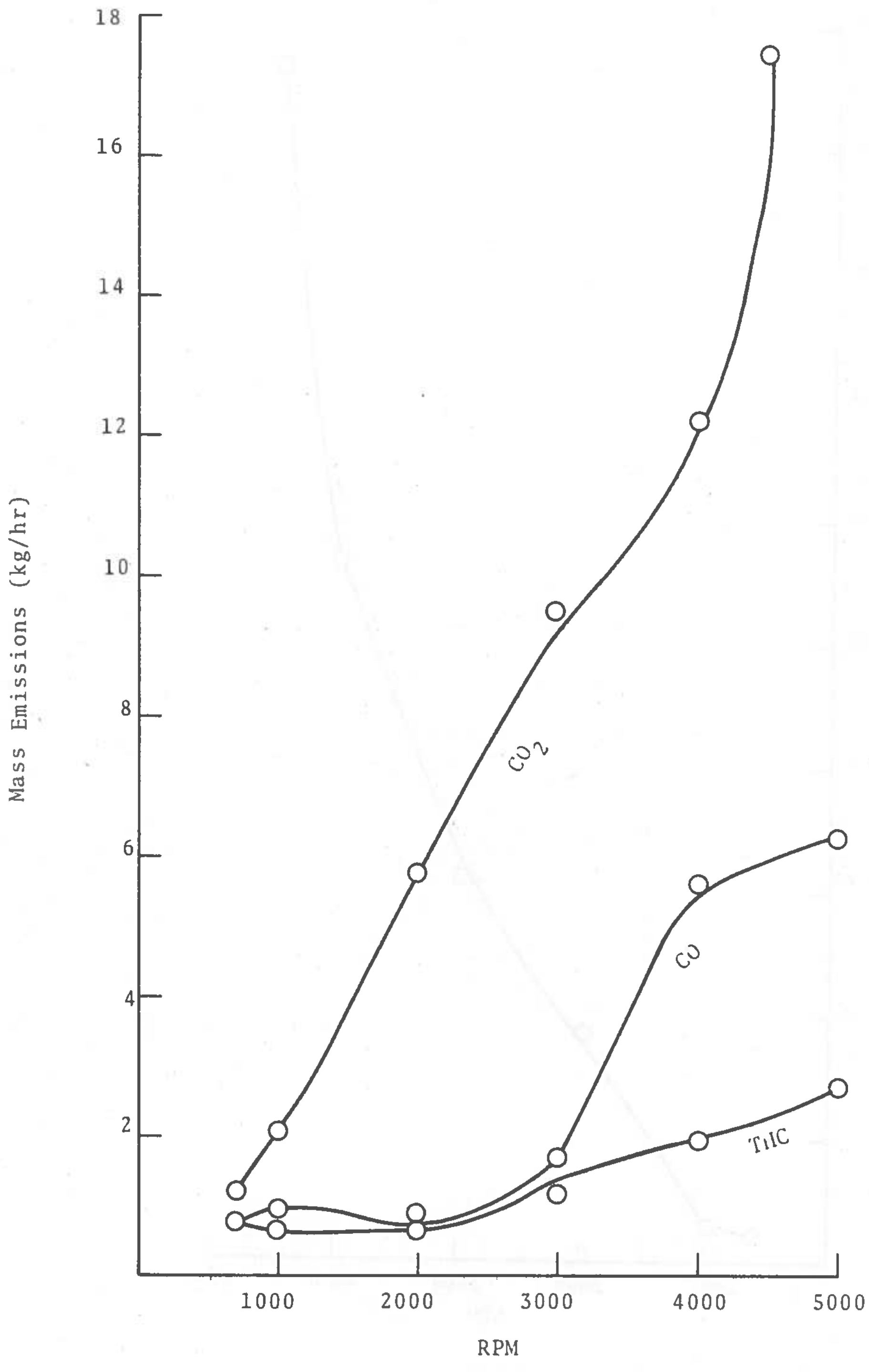


Figure 47. Average Mass Emissions (1974 Evinrude, 40 HP)

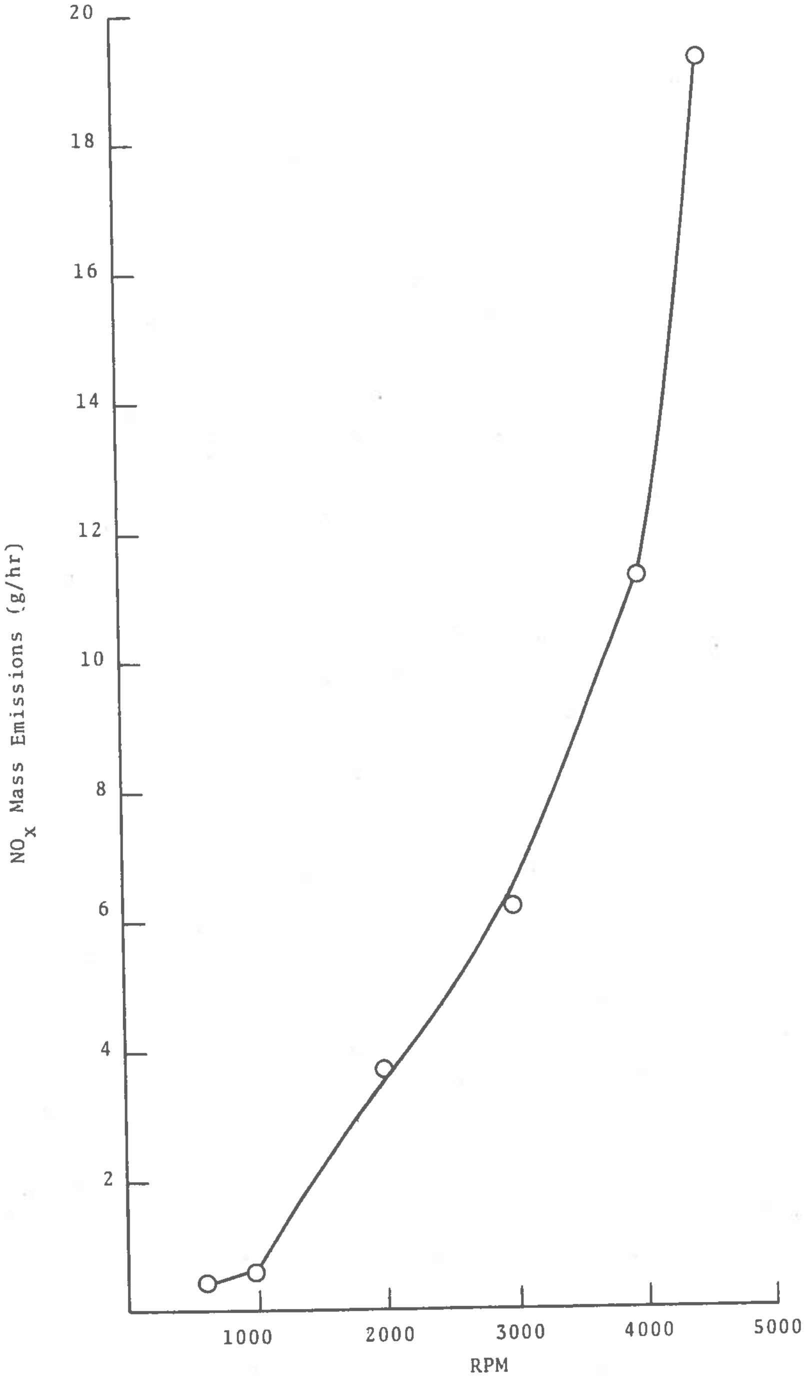


Figure 48. Average NO_x Emissions (1974 Evinrude, 40 HP)

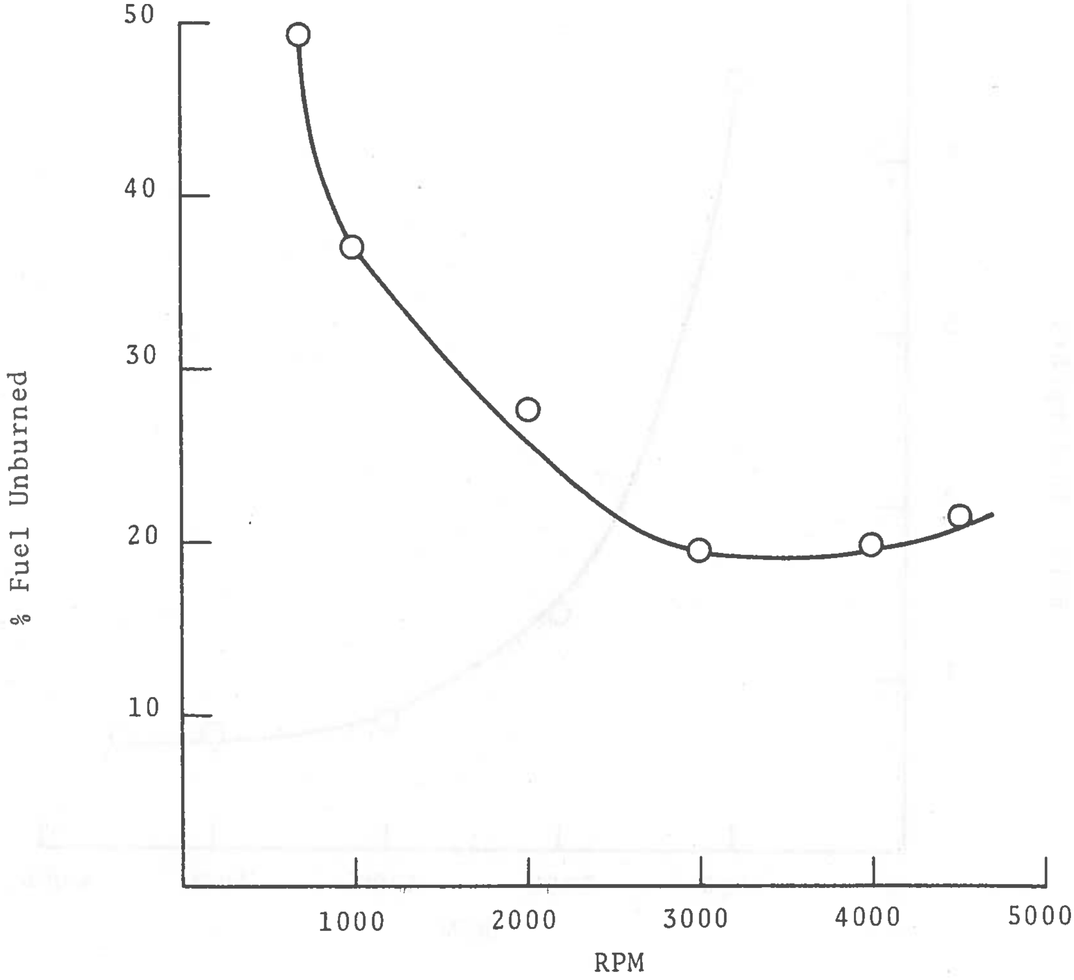


Figure 49. Average Percent Fuel Unburned (1974 Evinrude, 40 HP)

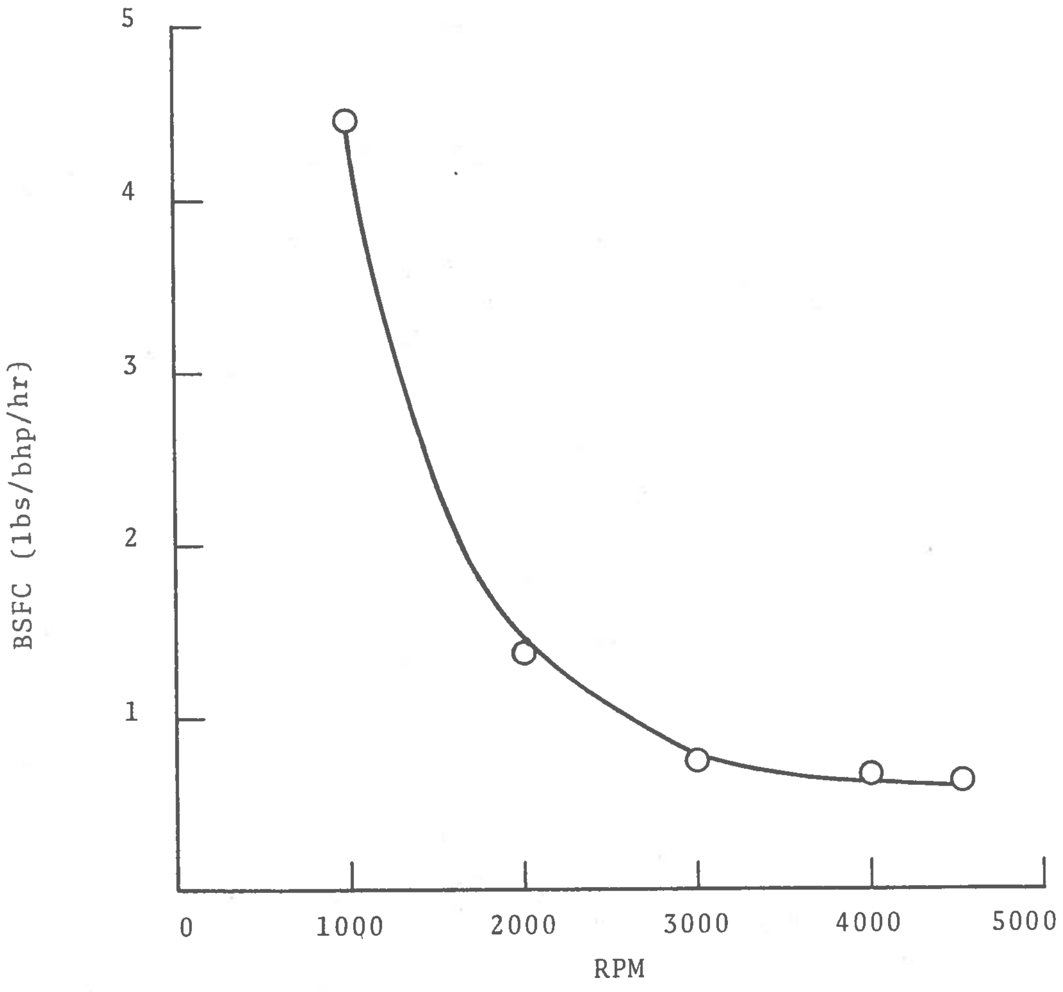


Figure 50. Brake Specific Fuel Consumption (1974 Evinrude, 40 HP)

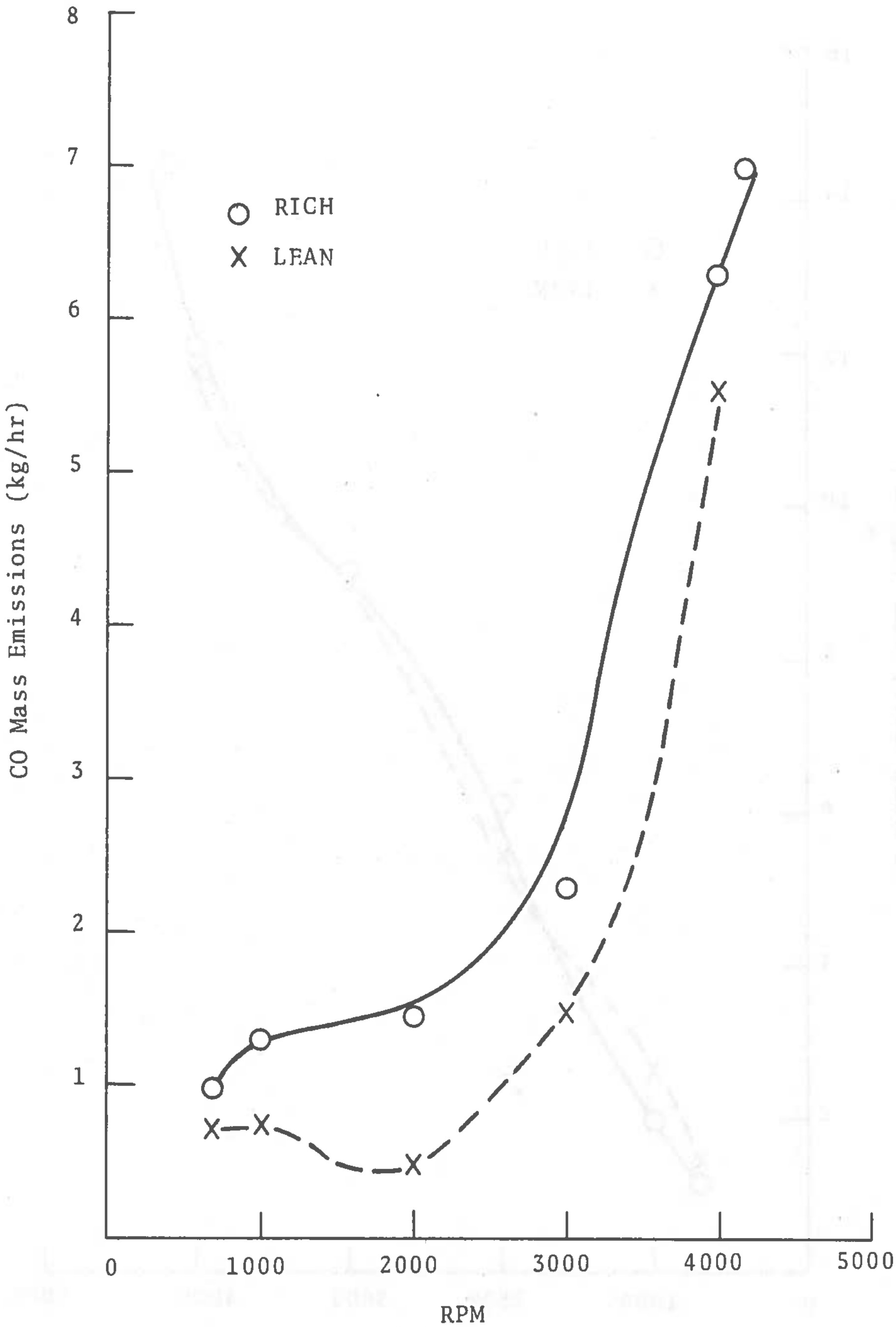


Figure 51. Average CO Emissions--Rich Versus Lean Carburetion (1974 Evinrude, 40 HP)

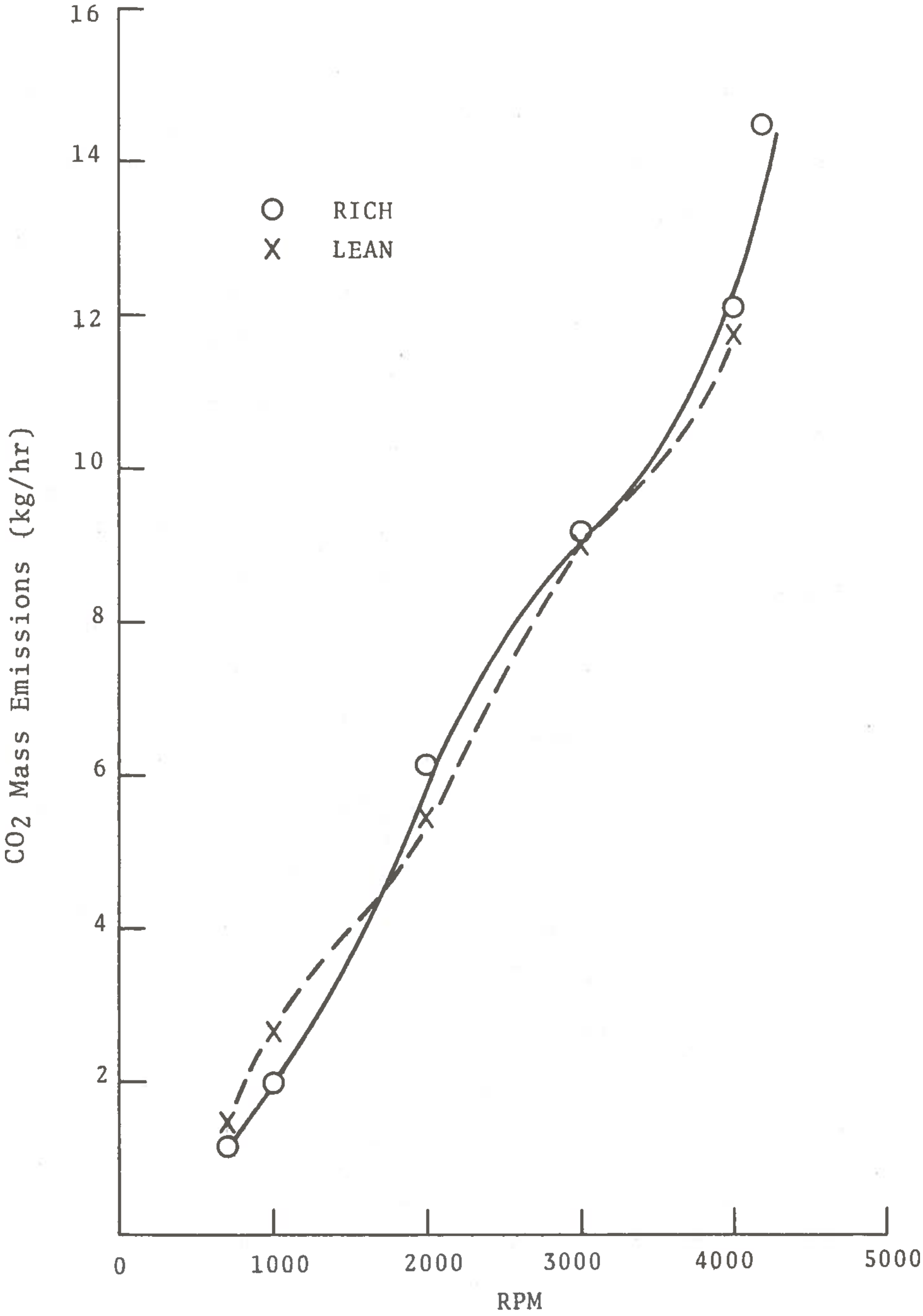


Figure 52. Average CO_2 Emissions--Rich Versus Lean Carburetion (1974 Evinrude, 40 HP)

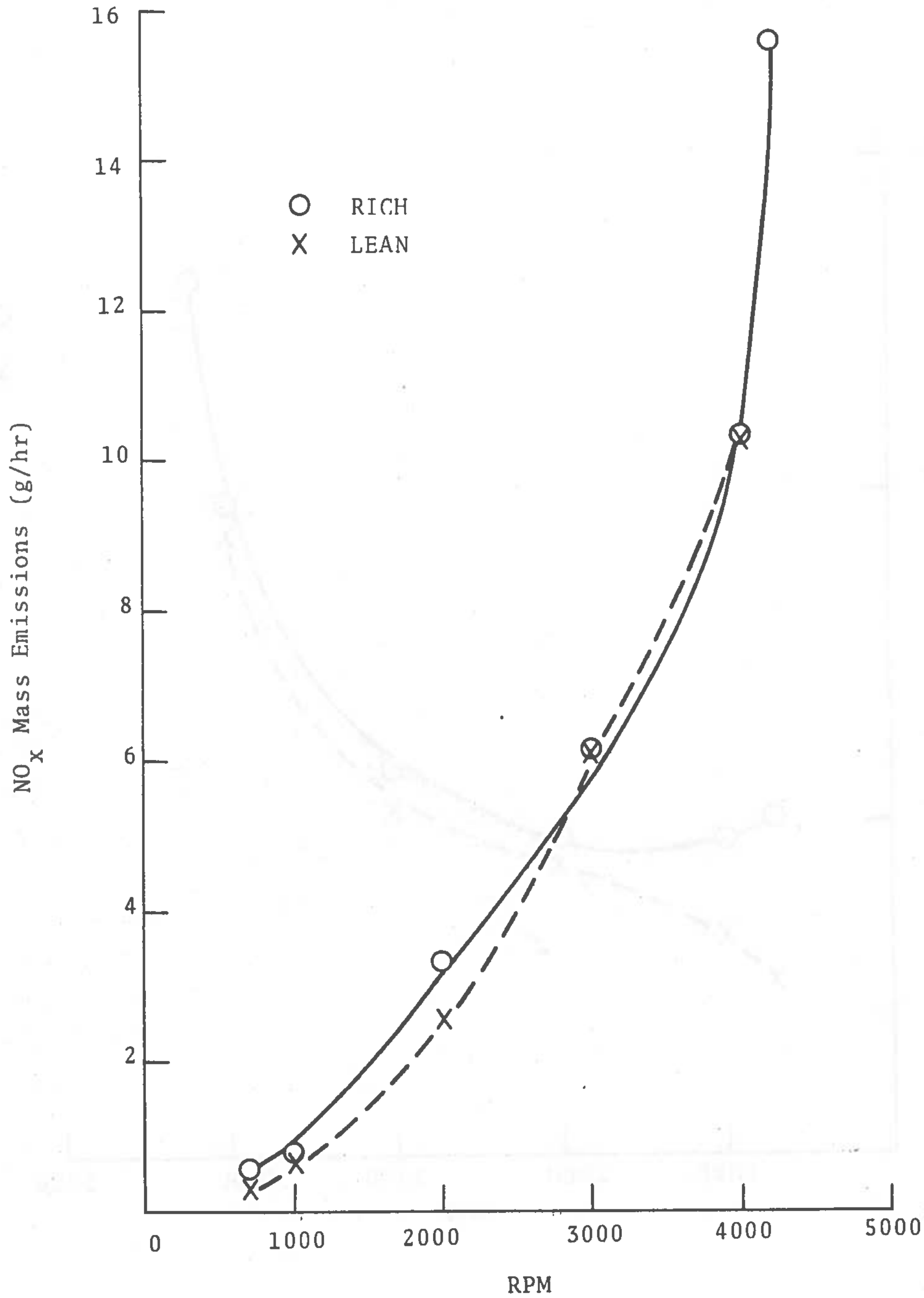


Figure 53. Average NO_x Emissions--Rich Versus Lean Carburetion (1974 Evinrude, 40 HP)

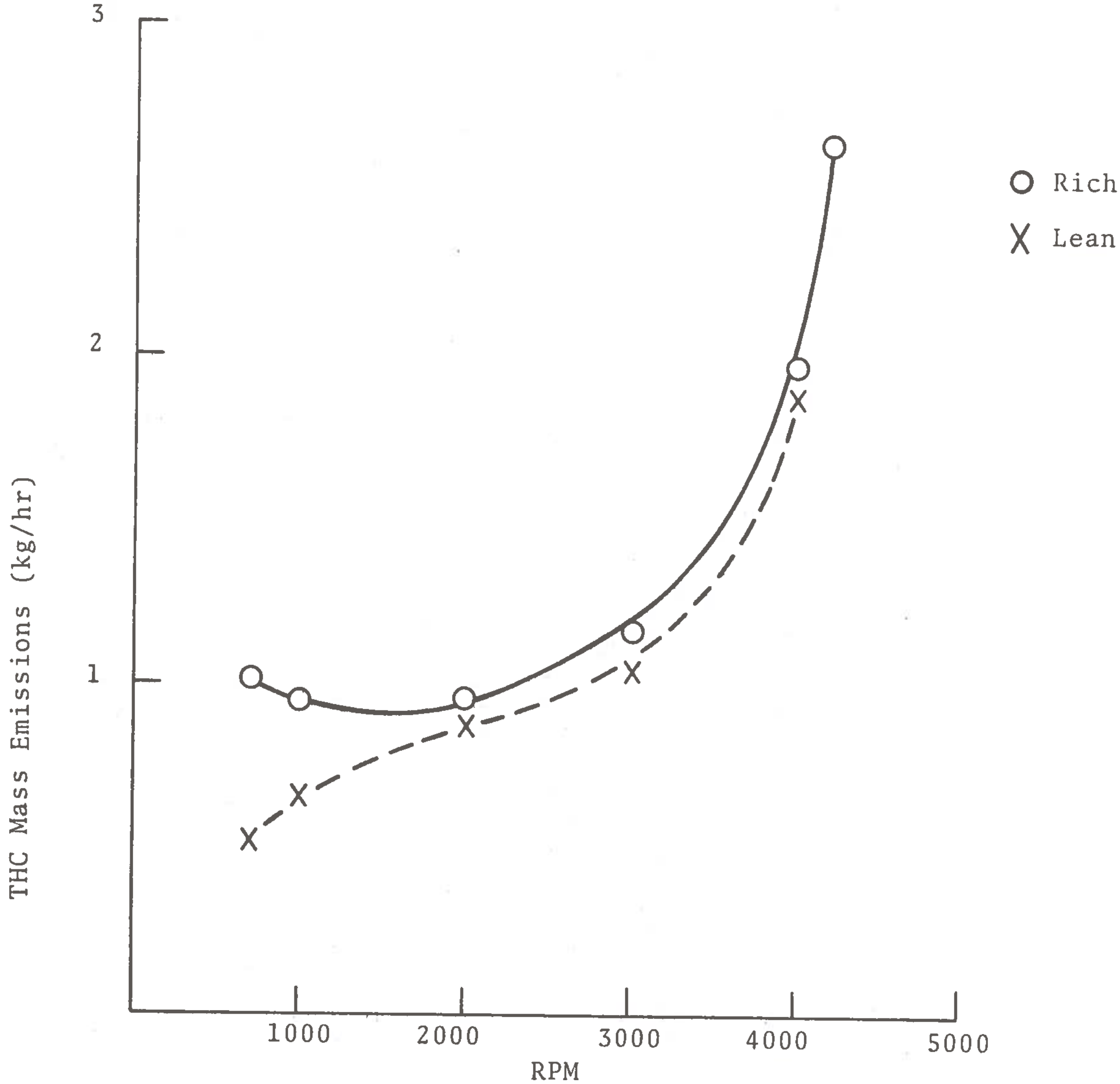


Figure 54. Average THC Emissions--Rich Versus Lean Carburetion (1974 Evinrude, 40 HP)

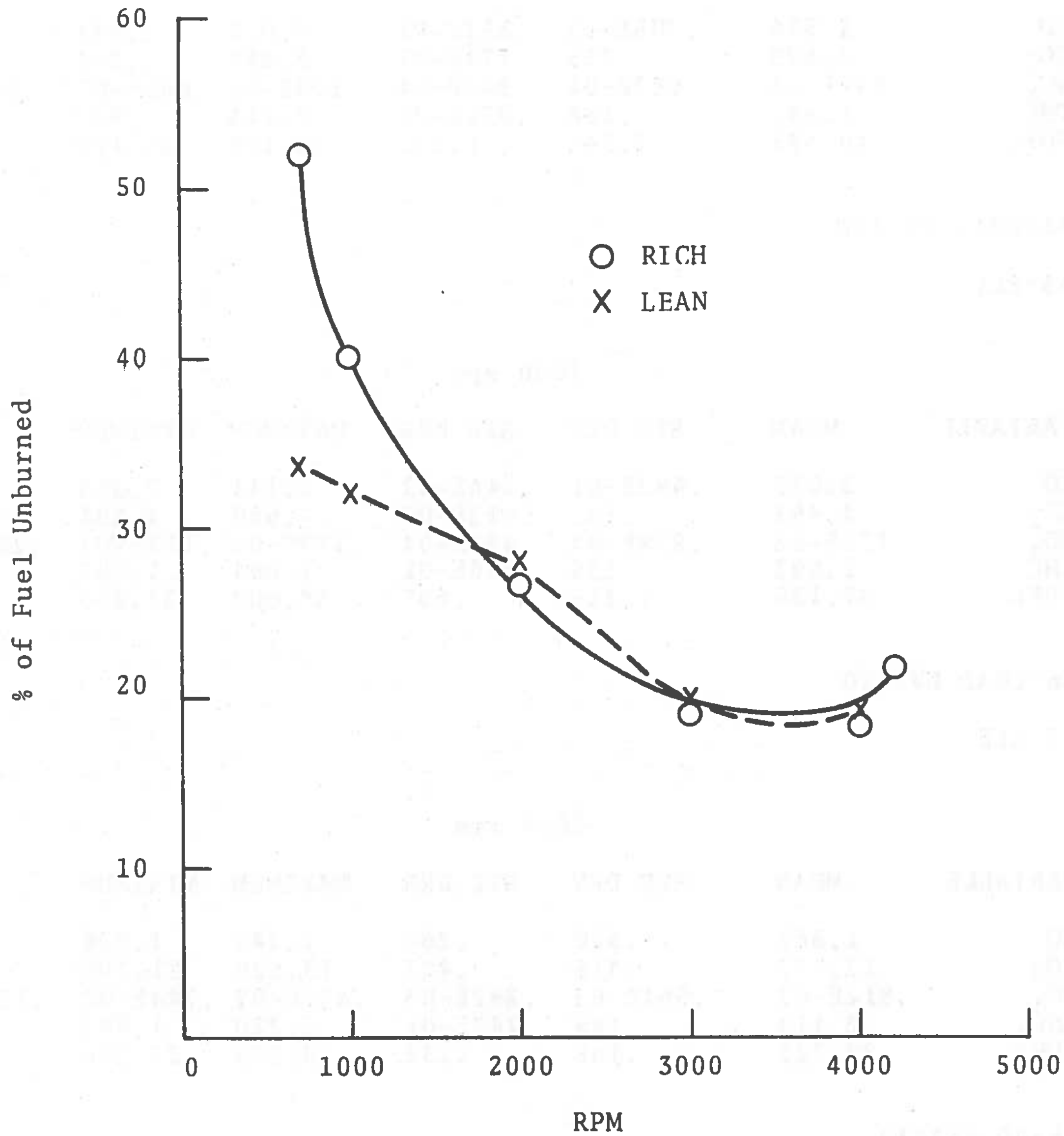


Figure 55. Average Percent Fuel Unburned--Rich Versus Lean Carburetion (1974 Evinrude, 40 HP)

TABLE 4. MASS EMISSIONS DATA FOR 1974 EVINRUDE AT MID-CARBURETOR SETTING (LBS/HR)

700 rpm

VARIABLE	MEAN	STD DEV	STD ERR	MAXIMUM	MINIMUM	RANGE
CO	1.916	.705E-01	.352E-01	2.010	1.844	.166
CO_2	2.689	.155	.774E-01	2.883	2.504	.379
NO_x	.944E-03	.687E-04	.343E-04	.100E-02	.860E-03	.142E-03
THC	1.987	.186	.931E-01	2.248	1.822	.426
FUEL	49.525	2.545	1.272	52.100	46.400	5.700

34>LOAD EV7410

35>ELE

1000 rpm

VARIABLE	MEAN	STD DEV	STD ERR	MAXIMUM	MINIMUM	RANGE
CO	2.075	.492E-01	.246E-01	2.141	2.035	.106
CO_2	4.463	.182	.912E-01	4.680	4.294	.386
NO_x	.129E-02	.878E-04	.439E-04	.139E-02	.118E-02	.211E-03
THC	1.692	.138	.600E-01	1.894	1.593	.301
FUEL	37.125	1.215	.607	38.600	35.900	2.700

36>LOAD EV7420

37>ELE

2000 rpm

VARIABLE	MEAN	STD DEV	STD ERR	MAXIMUM	MINIMUM	RANGE
CO	1.562	.520	.260	2.249	1.036	1.213
CO_2	12.777	.815	.407	13.620	11.700	1.920
NO_x	.812E-02	.564E-03	.282E-03	.879E-02	.744E-02	.135E-02
THC	2.119	.149	.747E-01	2.220	1.903	.317
FUEL	27.725	.465	.232	28.300	27.300	1.000

38>AD EV7430

TABLE 4. MASS EMISSIONS DATA FOR 1974 EVINRUDE AT MID-CARBURETOR SETTING (LBS/HR) (CONTINUED)

39>ELE

3000 rpm

VARIABLE	MEAN	STD DEV	STD ERR	MAXIMUM	MINIMUM	RANGE
CO	3.848	.632	.316	4.523	3.013	1.510
CO_2	20.555	1.361	.680	21.830	18.800	3.030
NO_x	.138E-01	.147E-02	.735E-03	.154E-01	.124E-01	.295E-02
THC	2.378	.795E-01	.398E-01	2.491	2.319	.172
FUEL	19.375	.236	.118	19.700	19.200	.500

40>LOAD EV7440

41>ELE

4000 rpm

VARIABLE	MEAN	STD DEV	STD ERR	MAXIMUM	MINIMUM	RANGE
CO	12.662	.891	.446	13.590	11.860	1.730
CO_2	26.877	1.570	.785	27.800	24.530	3.270
NO_x	.249E-01	.623E-03	.312E-03	.257E-01	.243E-01	.144E-02
THC	4.362	.395	.197	4.938	4.054	.884
FUEL	19.950	1.396	.698	21.300	18.600	2.700

42>LOS←AD EV7445

ELE

43>

4500 rpm

VARIABLE	MEAN	STD DEV	STD ERR	MAXIMUM	MINIMUM	RANGE
CO	13.787	1.404	.702	14.990	12.160	2.830
CO_2	38.420	1.424	.712	40.150	36.780	3.370
NO_x	.426E-01	.117E-02	586E-03	.442E-01	.415E-01	.274E-02
THC	6.069	.565	.283	6.681	5.315	1.366
FUEL	21.250	1.207	.603	22.600	19.700	2.900

TABLE 5. CONFIDENCE LEVEL (90%, TWO-SIDED TEST) DATA FOR 1974 EVINRUDE (LBS/HR)

```
19>SAVE EV74AV
OLD FILE - OK? Y
20>LOAD EV7470

21>CONF
VARIABLE:  CO
MEAN:  1.91575
STANDARD DEVIATION:  7.046690E-02
STANDARD ERROR OF MEAN:  3.523345E-02
ONE-SIDED OR TWO-SIDED TEST:  TWO
CONFIDENCE LEVEL(S) (%):90,90

CONFIDENCE LEVEL   90.00%, TWO-SIDED TEST
LOWER BOUND:     1.83283
UPPER BOUND:     1.99867
22>CONF CO2

MEAN:  2.68875
STANDARD DEVIATION:  .154832
STANDARD ERROR OF MEAN:  7.741595E-02
ONE-SIDED OR TWO-SIDED TEST:  TWO
CONFIDENCE LEVEL(S) (%):90,90

CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:   2.50656
UPPER BOUND    2.87094

CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:   2.50656
UPPER BOUND:   2.87094
23>CONF NOx
```

TABLE 5. CONFIDENCE LEVEL (90%, TWO-SIDED TEST) DATA FOR 1974 EVINRUDE (LBS/HR)(CONTINUED)

```
MEAN:  9.436500E-04
STANDARD DEVIATION:  6.869379E-05
STANDARD ERROR OF MEAN:  3.434689E-05

ONE-SIDED OR TWO-SIDED TEST:  TWO

CONFIDENCE LEVEL(S) (%):90,90


CONFIDENCE LEVEL 90.00%,  TWO-SIDED TEST
LOWER BOUND:  8.628190E-04
UPPER BOUND:  1.024481E-03


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND   8.628190E-04
UPPER BOUND:  1.024481E-03

24>CONF THC


MEAN:  1.98700
STANDARD DEVIATION:  .186193
STANDARD ERROR OF MEAN:  9.309672E-02

ONE-SIDED OR TWO-SIDED TEST:  TWO

CONFIDENCE LEVEL(S) (%):90,90


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:  1.76791
UPPER BOUND:   2.20609

CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:   1.76791
UPPER BOUND    2.20609

25>CONF FUEL


MEAN:  49.5250
STANDARD DEVIATION:  2.54477
STANDARD ERROR OF MEAN: 1.27238

ONE-SIDED OR TWO-SIDED TEST:  TWO

CONFIDENCE LEVEL(S) (%):90,90


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:   46.5306
UPPER BOUND:   52.5194
```

TABLE 5. CONFIDENCE LEVEL (90%, TWO-SIDED TEST) DATA FOR 1974 EVINRUDE (LBS/HR)(CONTINUED)

```
CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:   46.5306
UPPER BOUND:   52.5194

26>LOAD EV7410

27>CONF CO


MEAN:  2.07500
STANDARD DEVIATION:  4.920027E-02
STANDARD ERROR OF MEAN:  2.460014E-02

ONE-SIDED OR TWO-SIDED TEST:  TWO

CONFIDENCE LEVEL(S) (%):90,90


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:   2.01711
UPPER BOUND:   2.13289


CONFIDENCE LEVEL  90.00%, TWO-SIDED TEST
LOWER BOUND:    2.01711
UPPER BOUND:    2.13289

28>CONF CO2


MEAN:  4.6300
STANDARD DEVIATION:  .182300
STANDARD ERROR OF MEAN:  9.115006E-02

ONE-SIDED OR TWO-SIDED TEST:  TWO

CONFIDENCE LEVEL(S) (%):90,90


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:   4.24849
UPPER BOUND:   4.67751


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:   4.24849
UPPER BOUND:   4.67751
```

TABLE 5. CONFIDENCE LEVEL (90%, TWO-SIDED TEST) DATA FOR 1974 EVINRUDE (LBS/HR)(CONTINUED)

```
29>CONF NOx

TWO
MEAN:  1.287250E-03
STANDARD DEVIATION:   8.778145E-05
STANDARD ERROR OF MEAN:   4.389073E-05

ONE-SIDED OR TWO-SIDED TEST:

CONFIDENCE LEVEL(S) (%):90,90


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:  1.183959E-03
UPPER BOUND:  1.390541E-03


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:  1.183959E-03
UPPER BOUND:  1.390541E-03

30>CC←ONF THC


T
MEAN:  1.69225
STANDARD DEVIATION:   .137909
STANDARD ERROR OF MEAN:   6.895454E-02

ONE-SIDED OR TWO-SIDED TEST:  TWO

CONFIDENCE LEVEL(S) (%):90,90


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:   1.52997
UPPER BOUND:   1.85453


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:   1.52997
UPPER BOUND:   1.85453

31>CONF ↑
LOAD EV7420
```

TABLE 5. CONFIDENCE LEVEL (90%, TWO-SIDED TEST) DATA FOR 1974 EVINRUDE (LBS/HR)(CONTINUED)

32>CONF CO

MEAN: 1.56200
STANDARD DEVIATION: .520412
STANDARD ERROR OF MEAN: .260206

ONE-SIDED OR TWO-SIDED TEST: TWO,90,90

CONFIDENCE LEVEL(S) (%):90,90

CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND: .949639
UPPER BOUND: 2.17436

CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND: .949639
UPPER BOUND: 2.17436

33>CONF CO_2

MEAN: 12.7775
STANDARD DEVIATION: .814632
STANDARD ERROR OF MEAN: .407316

ONE-SIDED OR TWO-SIDED TEST: TWO

CONFIDENCE LEVEL(S) (%):90,90

CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND: 11.8189
UPPER BOUND: 13.7361

CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND: 11.8189
UPPER BOUND 13.7361

34>CONF NO_x

MEAN: 8.121250E-03
STANDARD DEVIATION: 5.640877E-04
STANDARD ERROR OF MEAN: 2.820438E-04

ONE-SIDED OR TWO-SIDED TEST: TWO

CONFIDENCE LEVEL(S) (%):90,90

TABLE 5. CONFIDENCE LEVEL (90%, TWO-SIDED TEST) DATA FOR 1974 EVINRUDE (LBS/HR)(CONTINUED)

```
CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:  7.457496E-03
UPPER BOUND:  8.785004E-03


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:  7.457496E-03
UPPER BOUND:  8.785004E-03

35>CONF THC


MEAN:  2.11925
STANDARD DEVIATION:  .149384
STANDARD ERROR OF MEAN:  7.469201E-02

ONE-SIDED OR TWO-SIDED TEST:  TWO

CONFIDENCE LEVEL(S) (%):90,90


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:   1.94347
UPPER BOUND:   2.29503


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:   1.94347
UPPER BOUND:   2.29503

36>CONF↑
LOAD EV73←430

37>CONF CO


NOT A VARIABLE NAME.

VARIABLE:  WO

NOT A VARIABLE NAME.

VARIABLE:  CONF CO

NOT A VARIABLE NAME.

VARIABLE:  CO

NOT A VARIABLE NAME.
```

TABLE 5. CONFIDENCE LEVEL (90%, TWO-SIDED TEST) DATA FOR 1974 EVINRUDE (LBS/HR)(CONTINUED)

```
VARIABLE:  LIST

NOT A VARIABLE NAME.

VARIABLE:  CO2


MEAN:  20.5550
STANDARD DEVIATION:  1.36050
STANDARD ERROR OF MEAN:  .680251

ONE-SIDED OR TWO-SIDED TEST:  TWO

CONFIDENCE LEVEL(S) (%):90,90

CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:   18.9541
UPPER BOUND:   22.1559


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:   18.9541
UPPER BOUND:   22.1559

38>CONF CO


MEAN:  3.84850
STANDARD DEVIATION:  .632395
STANDARD ERROR OF MEAN:  .316198

ONE-SIDED OR TWO-SIDED TEST:  TWO

CONFIDENCE LEVEL(S) (%):90,90


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:   3.10437
UPPER BOUND:   4.59263


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:   3.10437
UPPER BOUND:   4.59263

39>CONF NOx


MEAN:  1.384750E-02
STANDARD DEVIATION:  1.469544E-03
STANDARD ERROR OF MEAN:  7.347718E-04
```

TABLE 5. CONFIDENCE LEVEL (90%, TWO-SIDED TEST) DATA FOR 1974 EVINRUDE (LBS/HR)(CONTINUED)

```
ONE-SIDED OR TWO-SIDED TEST: TWO

CONFIDENCE LEVEL(S) (%):90,90


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:  1.211831E-02
UPPER BOUND:  1.557669E-02


CONFIDENCE LEVEL 90.00%, TWO SIDED TEST
LOWER BOUND:  1.211831E-02
UPPER BOUND:  1.557669E-02

40>CONF THC


MEAN:  2.37775
STANDARD DEVIATION:  7.950419E-02
STANDARD ERROR OF MEAN:  3.975210E-02

ONE-SIDED OR TWO-SIDED TEST:  TWO

CONFIDENCE LEVEL(S) (%):90,90


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:   2.28420
UPPER BOUND:   2.47130

CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:   2.28420
UPPER BOUND:   2.47130

41>LOAD EV7440

42>CONF CO


MEAN:  12.6625
STANDARD DEVIATION:  .891305
STANDARD ERROR OF MEAN: .445653

ONE-SIDED OR TWO-SIDED TEST:  TWO

CONFIDENCE LEVEL(S) (%):90,90


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:   11.6137
UPPER BOUND:   13.7113
```

TABLE 5. CONFIDENCE LEVEL (90%, TWO-SIDED TEST) DATA FOR 1974 EVINRUDE (LBS/HR)(CONTINUED)

```
CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:    11.6137
UPPER BOUND:    13.7113

43>CONF CO2


MEAN:  26.8775
STANDARD DEVIATION:  1.57025
STANDARD ERROR OF MEAN:  .785126

ONE-SIDED OR TWO-SIDED TEST:  TWO

CONFIDENCE LEVEL(S) (%):90,90


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:    25.0298
UPPER BOUND:    28.7252


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:    25.0298
UPPER BOUND:    28.7252

44>CONF NOx

MEAN:  2.493750E-02
STANDARD DEVIATION:  6.232375E-04
STANDARD ERROR OF MEAN:  3.116188E-04

ONE-SIDED OR TWO-SIDED TEST:  TWO

CONFIDENCE LEVEL(S) (%):90,90

CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:  2.420415E-02
UPPER BOUND:  2.567085E-02

CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:  2.420415E-02
UPPER BOUND:  2.567085E-02

45>CONF THC


MEAN:  4.36250
STANDARD DEVIATION:  .394726
STANDARD ERROR OF MEAN:  .197363
```

TABLE 5. CONFIDENCE LEVEL (90%, TWO-SIDED TEST) DATA FOR 1974 EVINRUDE (LBS/HR)(CONTINUED)

```
ONE-SIDED OR TWO-SIDED TEST:  TWO

CONFIDENCE LEVEL(S) (%):90,90


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:   3.89803
UPPER BOUND:   4.82697


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:   3.89803
UPPER BOUND:   4.82697

46>CONF ↑
LOAD EV7445

47>CONF CO


MEAN:  13.7875
STANDARD DEVIATION:  1.40415
STANDARD ERROR OF MEAN:  .702073

ONE-SIDED OR TWO-SIDED TEST:  TWO

CONFIDENCE LEVEL(S) (%):90,90


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:   12.1353
UPPER BOUND:   15.4397


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:   12.1353
UPPER BOUND:   15.4397

48>CONF CO2


MEAN:  38.4200
STANDARD DEVIATION:  1.42391
STANDARD ERROR OF MEAN:  .711957

ONE-SIDED OR TWO-SIDED TEST:  TWO

CONFIDENCE LEVEL(S) (%):90,90
```

TABLE 5. CONFIDENCE LEVEL (90%, TWO-SIDED TEST) DATA FOR 1974 EVINRUDE (LBS/HR) (CONTINUED)

```
CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:    36.7445
UPPER BOUND:    40.0955


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:    36.7445
UPPER BOUND:    40.0955

49>CONF NOx


MEAN:  4.256750E-02
STANDARD DEVIATION:  1.171050E-03
STANDARD ERROR OF MEAN:  5.855250E-04

ONE-SIDED OR TWO-SIDED TEST:  TWO

CONFIDENCE LEVEL(S) (%):90,90


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:  4.118954E-02
UPPER BOUND:  4.394546E-02

CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:  4.118954E-02
UPPER BOUND:  4.394546E-02

50>CONF THC


MEAN;  6.06950
STANDARD DEVIATION:  .565163
STANDARD ERROR OF MEAN:  .282582

ONE-SIDED OR TWO-SIDED TEST:  TWO

CONFIDENCE LEVEL(S) (%):90,90

CONFIDENCE LEVEL 90%, TWO-SIDED TEST
LOWER BOUND:    5.40448
UPPER BOUND:    6.73452


CONFIDENCE LEVEL 90.00%, TWO-SIDED TEST
LOWER BOUND:    5.40448
UPPER BOUND:    6.73452
```

3.5 1972 MERCURY, 40 HP

The 1972 Mercury engine was new and required break-in as per Mercury specifications. The engine break-in schedule is given in Table 6.

TABLE 6. MERCURY ENGINE BREAK-IN SCHEDULE

Speed (rpm)	Load (hp)	Time (hr)
1000	0.00	1
2000	0.00	1
2500	0.00	1
1000	0.75	1.5
2000	4.00	1.5
3000	11.00	2
4000	22.00	.25
5000	40.00	.25

Speeds above 3000 rpm were maintained for as short periods as possible.

This engine ran smoothly over all power ranges. As with the new 1974 Evinrude, no tune-up was performed on this engine. The mass emission rates, percent of fuel unburned and the BSFC are given in Figures 56 through 59.

3.6 WATER/EXHAUST MIXING RESULTS

Using the equations given in Sections 2.9.2 and 2.9.3, along with temperature, pressure and corrections for water content of the gases, the average losses by mass to the water of CO, CO_2, NO_x, and THC were calculated. These loss percentages were then multiplied by the previously calculated mass emission rates (g/hr) to obtain the emissions retained in the water. The remainder of the emissions were discharged to the air. All the water mixing experiments were conducted with tuned engines, and a four-hole bubbler in the mixing tank. The water/exhaust mixing ratio was held constant at 4.45. The results of these experiments are given in Table 7. Table 8 shows the percent loss to the water for each of the emissions.

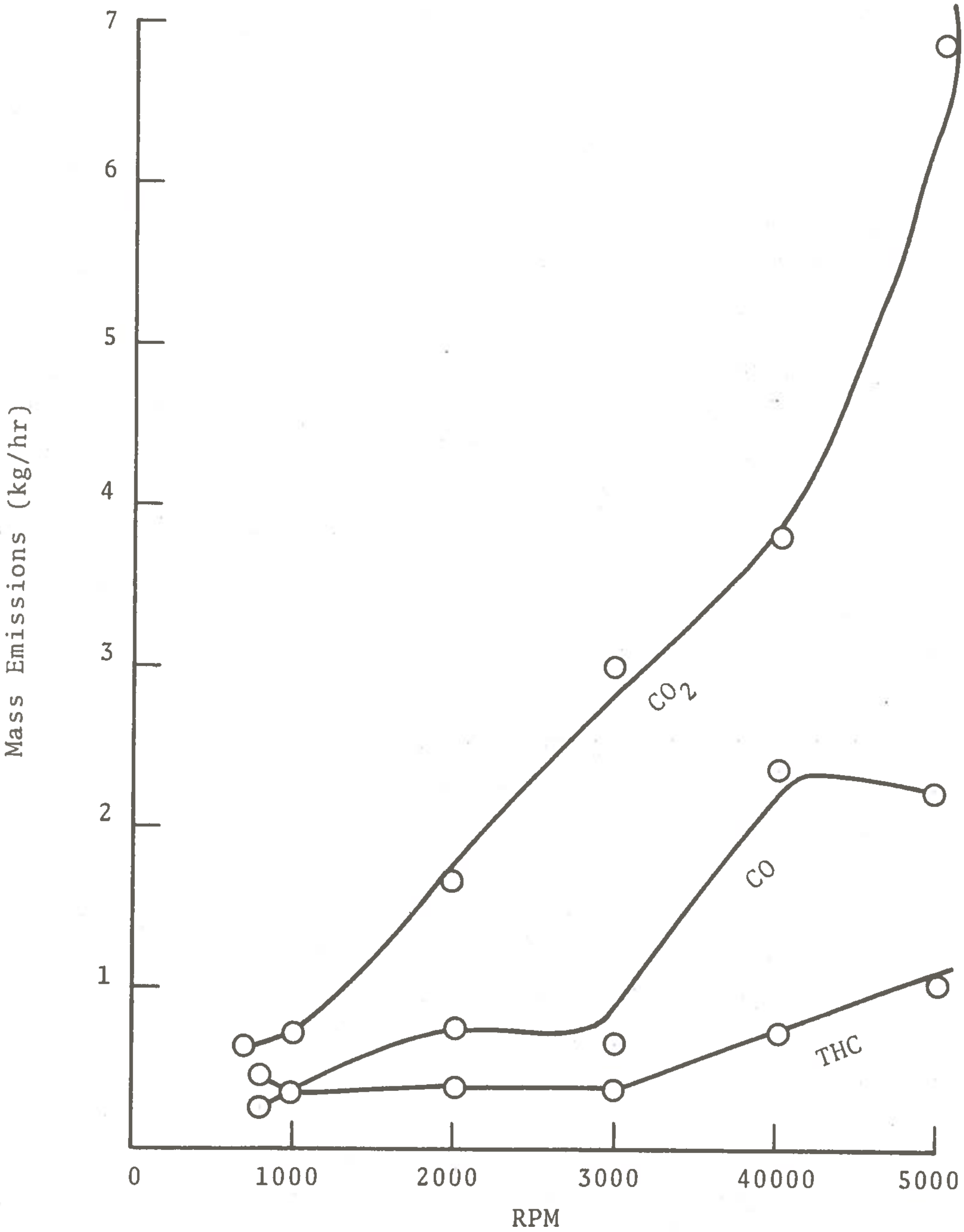


Figure 56. Average Mass Emissions (1972 Mercury, 40 HP)

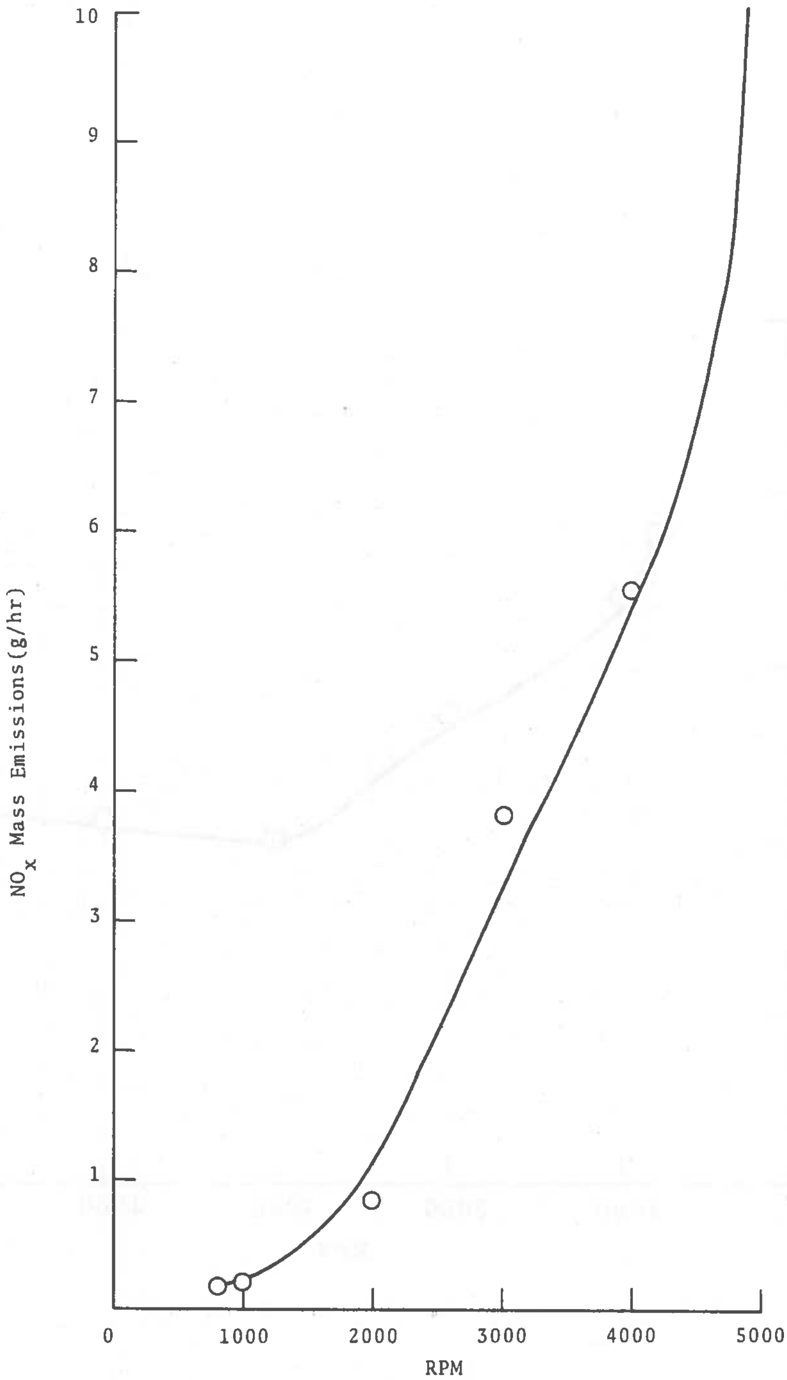


Figure 57. Average NO_x Emissions (1972 Mercury, 40 HP)

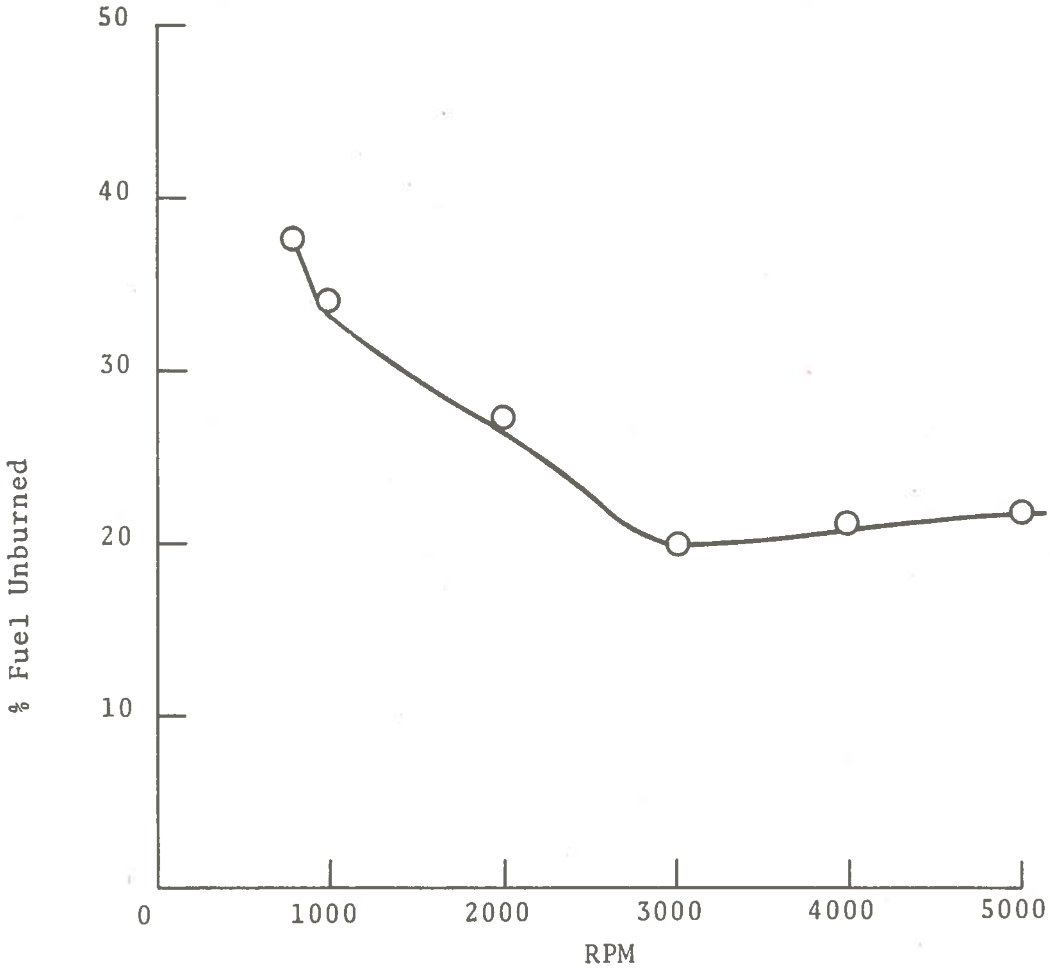


Figure 58. Average Percent Fuel Unburned (1972 Mercury, 40 HP)

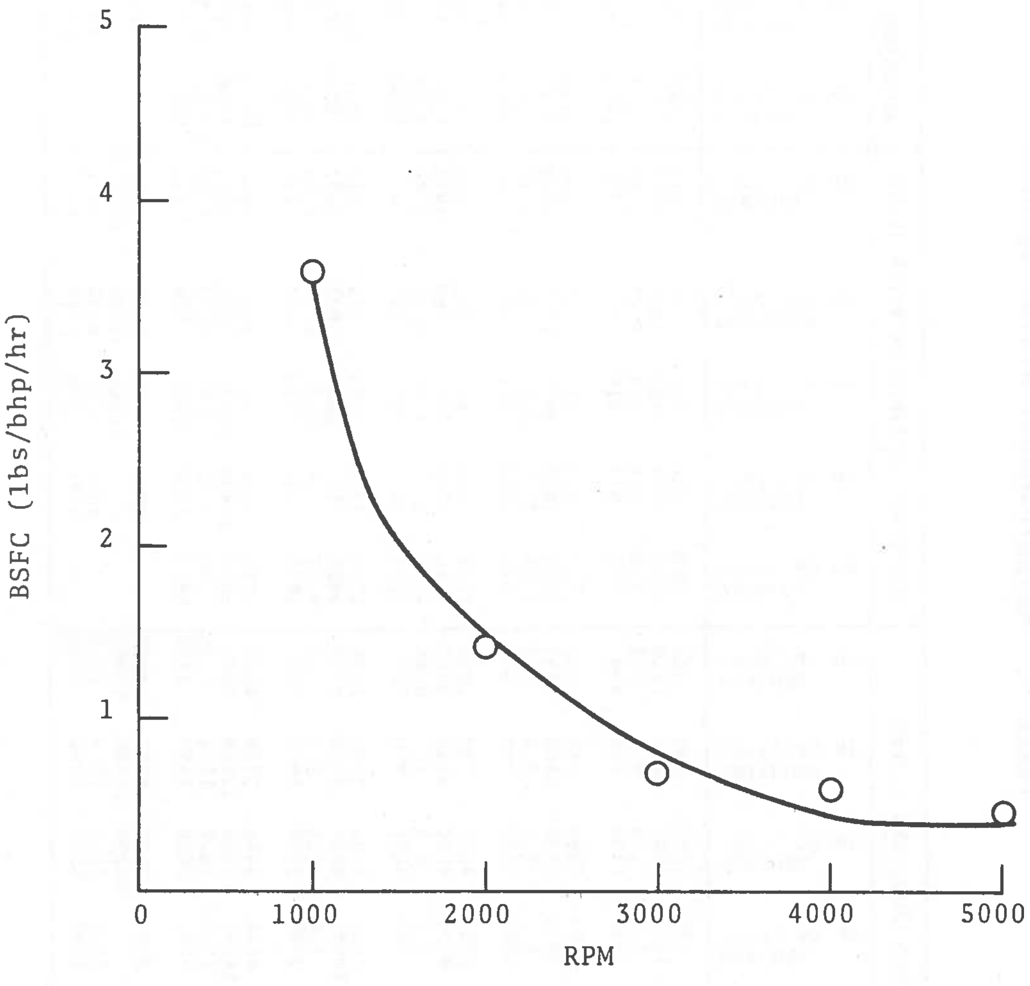


Figure 59. Brake Specific Fuel Consumption (1972 Mercury, 40 HP)

TABLE 7. WATER/EXHAUST MIXING RESULTS

MODE	GAS	MASS EMISSIONS (g/hr)					EMISSIONS RETAINED IN WATER (g/hr)					EMISSIONS VENTED TO AIR (g/hr)				
		JOHNSON 1959, 50 HP	MERCURY 1964, 65 HP	MERCURY 1962, 70 HP	EVINRUDE 1974, 40 HP	MERCURY 1972, 40 HP	JOHNSON 1959, 50 HP	MERCURY 1964, 65 HP	MERCURY 1962, 70 HP	EVINRUDE 1974, 40 HP	MERCURY 1972, 40 HP	JOHNSON 1959, 50 HP	MERCURY 1964, 65 HP	MERCURY 1962, 70 HP	EVINRUDE 1974, 40 HP	MERCURY 1972, 40 HP
1	CO	2850	700	1200	900	500	201	386	366	246	112	2649	314	834	654	388
	CO_2	7000	3125	2000	1200	1250	5230	2744	1483	1005	1062	1770	381	517	195	188
	NO_x	2.6	1.0	.75	0.4	0.2	1.2	0.6	0.4	0.23	0.12	1.4	0.4	0.35	0.17	0.08
	THC	3050	1550	1700	900	450	597	934	910	474	235	2453	616	790	426	215
2	CO	4500	750	2000	950	550	344	427	510	245	160	4156	323	1490	705	390
	CO_2	9125	3625	2900	2100	1400	6998	3093	2076	1715	1221	2127	532	824	385	179
	NO_x	3.0	1.2	1.1	0.6	0.2	1.35	0.77	0.55	0.24	0.12	1.65	0.43	0.55	0.36	0.08
	THC	3200	1780	2300	760	300	643	1033	1411	352	160	2557	747	889	408	140
3	CO	7000	1350	4400	700	1450	1123	624	846	142	502	5877	726	3554	558	948
	CO_2	9250	6750	4850	5750	3300	7145	5759	3507	4769	2933	2105	991	1343	981	367
	NO_x	4.5	2.5	2.5	1.7	0.85	1.96	1.36	1.05	0.24	C.36	2.54	1.14	1.45	1.46	0.49
	THC	7050	2250	3750	950	750	2641	1274	2135	452	426	4409	976	1615	498	324
4	CO	10000	4950	7500	1750	1250	1773	2221	1209	554	414	8227	2729	6291	1196	836
	CO_2	12500	10625	8400	9500	6000	9825	9132	5829	7928	5493	2675	1493	2571	1572	507
	NO_x	8.6	4.5	4.5	6.2	3.8	0.65	1.96	1.22	1.74	1.75	7.95	2.54	3.28	4.46	2.05
	THC	6150	2700	3800	1075	750	1825	1631	2116	483	441	4325	1069	1684	592	309
5	CO	7600	6650	9500	5750	4600	1747	8367	925	1662	1664	5853	2783	8575	4088	2936
	CO_2	20000	18000	13500	12200	7600	16052	15809	10292	10009	6816	3948	2191	3208	2191	784
	NO_x	18.5	12.0	10.8	11.1	5.55	.98	5.62	2.05	3.76	2.60	17.52	6.38	8.75	7.34	2.95
	THC	5800	3250	3050	1950	1450	1412	1508	1419	996	855	4388	1742	1631	954	595
6	CO	7650	9300	12600	6250	4200	-	5873	474	1837	1191	-	3427	12126	4413	3009
	CO_2	-	-	20200	17400	13800	-	-	14815	14706	11752	-	-	5385	2694	2048
	NO_x	-	27.0	21.0	19.3	20.8	-	13.8	5.39	6.82	10.1	-	13.2	15.61	12.48	10.7
	THC	4650	4500	3700	2500	2050	-	2986	1308	1309	1077	-	1514	2392	1191	973

TABLE 8. EMISSION LOSS IN WATER

MODE	GAS	LOSS IN WATER, %				
		JOHNSON 1959, 50 HP	MERCURY 1964, 65 HP	MERCURY 1962, 70 HP	EVINRUDE 1974, 40 HP	MERCURY 1972, 40 HP
1	CO	7.071	55.16	30.50	27.30	22.48
	CO_2	74.71	87.80	74.17	83.72	84.97
	NO_x	46.58	61.92	48.03	58.91	60.30
	THC	19.58	60.24	53.52	52.70	52.15
2	CO	7.656	56.96	25.50	25.84	29.10
	CO_2	76.69	85.32	71.59	81.66	87.24
	NO_x	45.14	63.87	50.01	40.02	59.16
	THC	20.10	58.06	61.35	46.28	53.33
3	CO	16.041	46.23	19.23	20.23	34.65
	CO_2	77.24	85.32	72.31	82.94	88.89
	NO_x	43.56	54.49	42.17	13.84	42.37
	THC	37.46	56.61	56.92	47.56	56.80
4	CO	17.729	44.87	16.12	31.67	33.10
	CO_2	78.60	85.95	69.39	83.45	91.55
	NO_x	7.58	43.62	27.20	28.06	46.11
	THC	29.68	60.41	55.68	44.93	58.83
5	CO	22.984	58.15	9.74	28.90	36.18
	CO_2	80.26	87.83	76.24	82.04	89.69
	NO_x	5.29	46.81	19.03	33.85	46.84
	THC	24.34	46.39	46.54	51.07	58.99
6	CO		63.15	3.76	29.40	28.35
	CO_2	84.82	88.81	73.34	84.52	85.16
	NO_x	61.07	51.20	25.66	35.33	48.43
	THC	-4.57	66.35	35.35	52.35	52.52

4. DISCUSSION OF TEST RESULTS

4.1 GENERAL

The emissions observed here are characteristic of over-scavanged, two-stroke cycle OE and the results are in generally good agreement with those reported by others (the older engines tested had crankcase exhaust drainage). In order to develop a better perspective on the mass emission rates from these engines, the CO, THC, and NO_x from the 1964 Mercury 65 hp engines are plotted against the emissions from a Fairbanks-Morse turbocharged 3600 hp diesel engine in the U.S Coast Guard service (Figure 60).

The CO and THC mass emission rates (kg/hr) of the 65 hp OE were approximately twice as high as the CO and THC from the 3600 hp diesel engine. The NO_x from the diesel engine, however, greatly exceeded that from the OE (diesel = kg, OE = g). These high NO_x levels from the diesel are indicative of the high flame temperatures in the combustion process.

Table 9 compares the exhaust emissions from the OE's to an average automotive gasoline-powered light duty vehicle. The pre-1968 automotive emissions are compared to the 1964, 65 hp Mercury and the 73-74 automotive emissions to the 1974, 40 hp Evinrude. Units are in grams per mile (g/mi).

TABLE 9. OUTBOARD MOTOR EXHAUST EMISSIONS COMPARED TO AUTO EMISSIONS

Pollutant	Auto(pre-1968) g/mi	1964 Mercury 65 hp (range) g/mi	Auto(1973-74) g/mi	1974 Evinrude 40 hp (range) g/mi
CO	88.3	80 - 210	19	170 - 219
THC	7.82	210 - 97	2.7	183 - 98
NO_x	3.33	0.1 - 0.4	2.3	.08 - .65

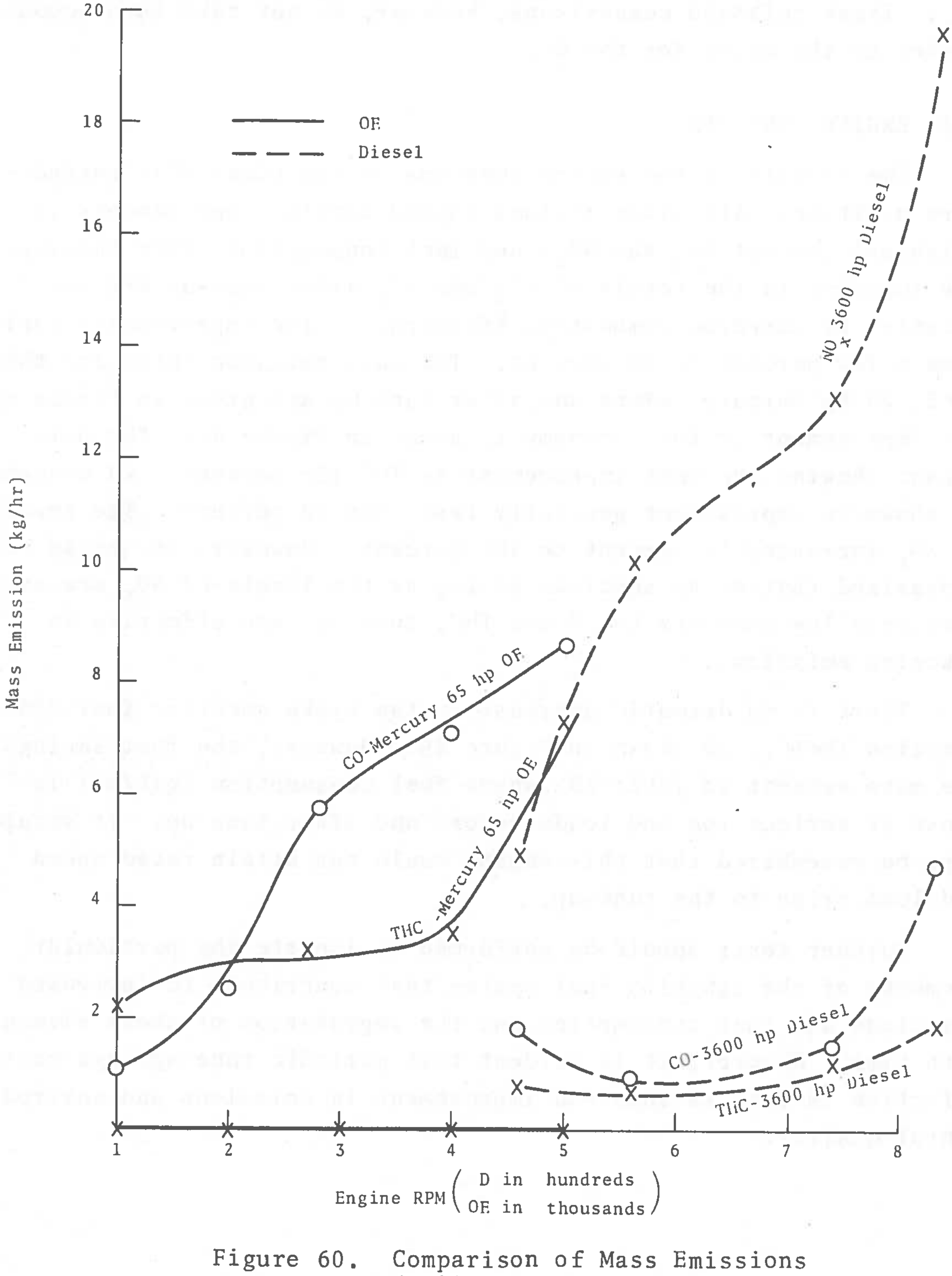


Figure 60. Comparison of Mass Emissions (3600 HP Diesel - 65 HP OE)

As with the diesel engine, the OE exceeded automotive engines in mass emission rates for CO and THC, but was considerably less in NO_x. These emission comparisons, however, do not take into account losses to the water for the OE.

4.2 ENGINE TUNE-UPS

The results of the engine tune-ups on the older OE's tested were positive. All older engines showed varying improvements in emissions (except CO_2 and NO_x) and fuel consumption after tune-up. The increase in the levels of CO_2 and NO_x after tune-up are indicative of improved combustion efficiency. The improvements varied from a few percent to 20 percent. The mass emission rates for the 1962, 70 hp Mercury before and after tune-up are given in Figure 61. The improvement in fuel economy is given in Figure 46. The pollutant showing the most improvement is THC (25 percent - 40 percent). CO shows an improvement generally less than 10 percent. The levels of NO_x increased 50 percent to 100 percent. However, it should be emphasized that on an absolute basis, as the levels of NO_x are exceedingly low compared to CO and THC, tune-ups are effective in lowering emissions.

There is no dramatic decrease in the brake specific fuel consumption (BSFC), as shown in Figure 45. However, the fuel savings are more evident in Table 10, where fuel consumption (gal/hr) is shown at various rpm and loads before and after tune-up. It should also be remembered that this engine could not attain rated speed and load prior to the tune-up.

Further tests should be performed to isolate the particular elements of the ignition-fuel system that contribute to increased emissions and fuel consumption and the degradation of these elements with time. However, it is evident that periodic tune-ups are cost-effective in fuel savings and improvement in emissions and environmental quality.

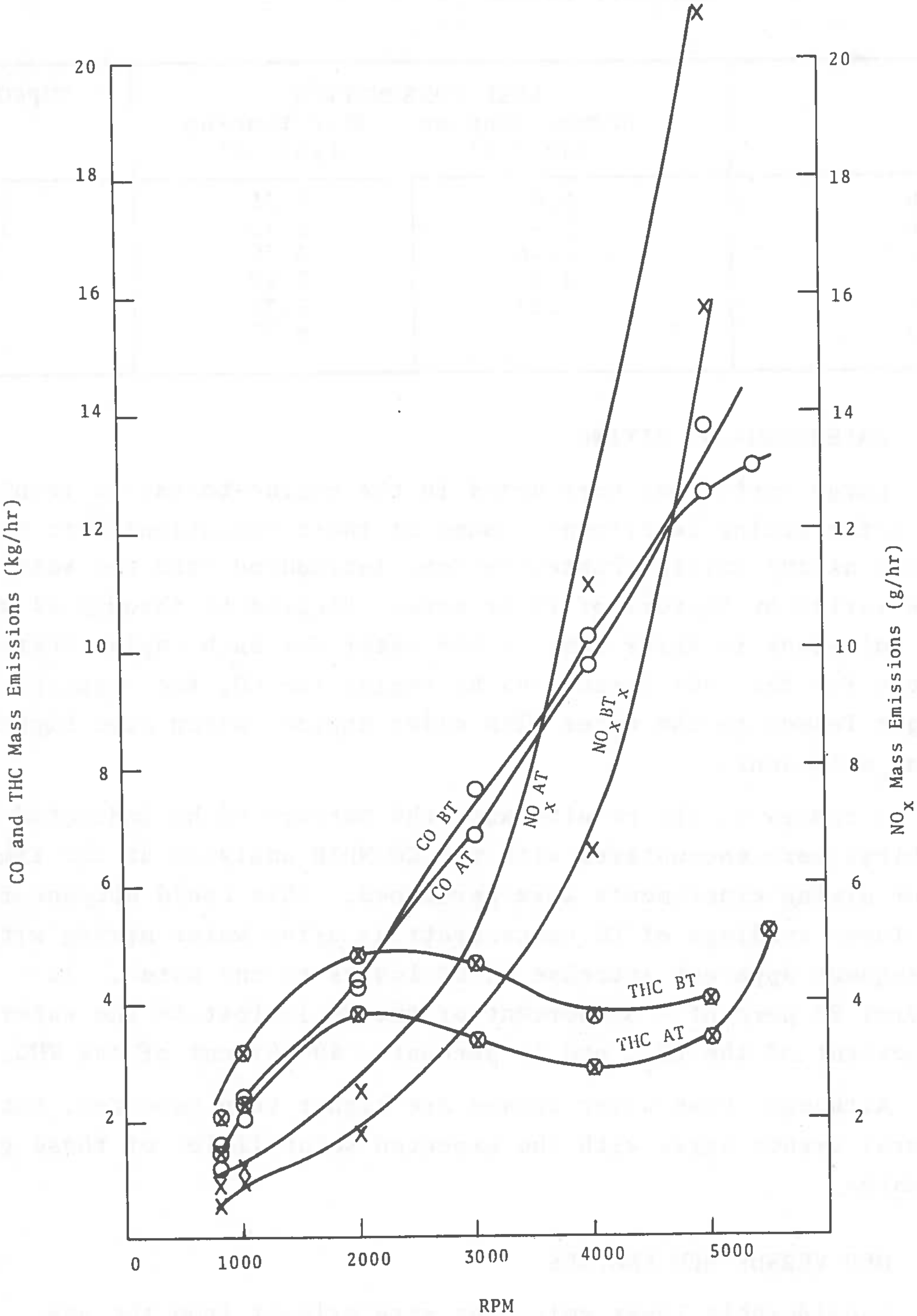


Figure 61. Effect of Tune-up on Mass Emissions (1962 Mercury, 70 HP)

TABLE 10. FUEL SAVINGS BY TUNING UP 1962 MERCURY, 70 HP, OUTBOARD ENGINE

RPM	FUEL CONSUMPTION Before tune-up (gal/hr)	After tune-up (gal/hr)	% IMPROVEMENT
1000	1.62	1.35	20.0
2000	2.80	2.45	14.3
3000	3.46	3.29	5.2
4000	4.25	3.92	8.4
5000	5.32	5.32	0
5500		6.47	-

4.3 WATER/EXHAUST MIXING

Large variations were noted in the engine-to-engine results in the water mixing experiment. Some of these variations were expected as the initial concentrations introduced into the water tank varied by factors of 20 or more. Figures 62 through 64 show the emissions in kg/hr lost to the water for each engine tested. Except for the 1964 Mercury 65 hp engine for CO, the results show larger losses to the water with older engines which have higher total emissions.

A review of the results with the Mercury 65 hp indicated that problems were encountered with the CO NDIR analyzer at the time the water mixing experiments were performed. This could account for the lower readings of CO concentrations after water mixing with the subsequent apparent increase in CO losses to the water. In general 20 percent - 30 percent of the CO is lost to the water, 80 percent of the CO_2, and 30 percent - 60 percent of the THC.

Although these water losses are higher than expected, the general trends agree with the expected solubilities of these gases in water.

4.4 OLD VERSUS NEW ENGINES

Considerably lower emissions were evident from the new engines tested in this study. This can be attributed, in part, to improved combustion chamber design and ignition systems, and crankcase drainage recycling.

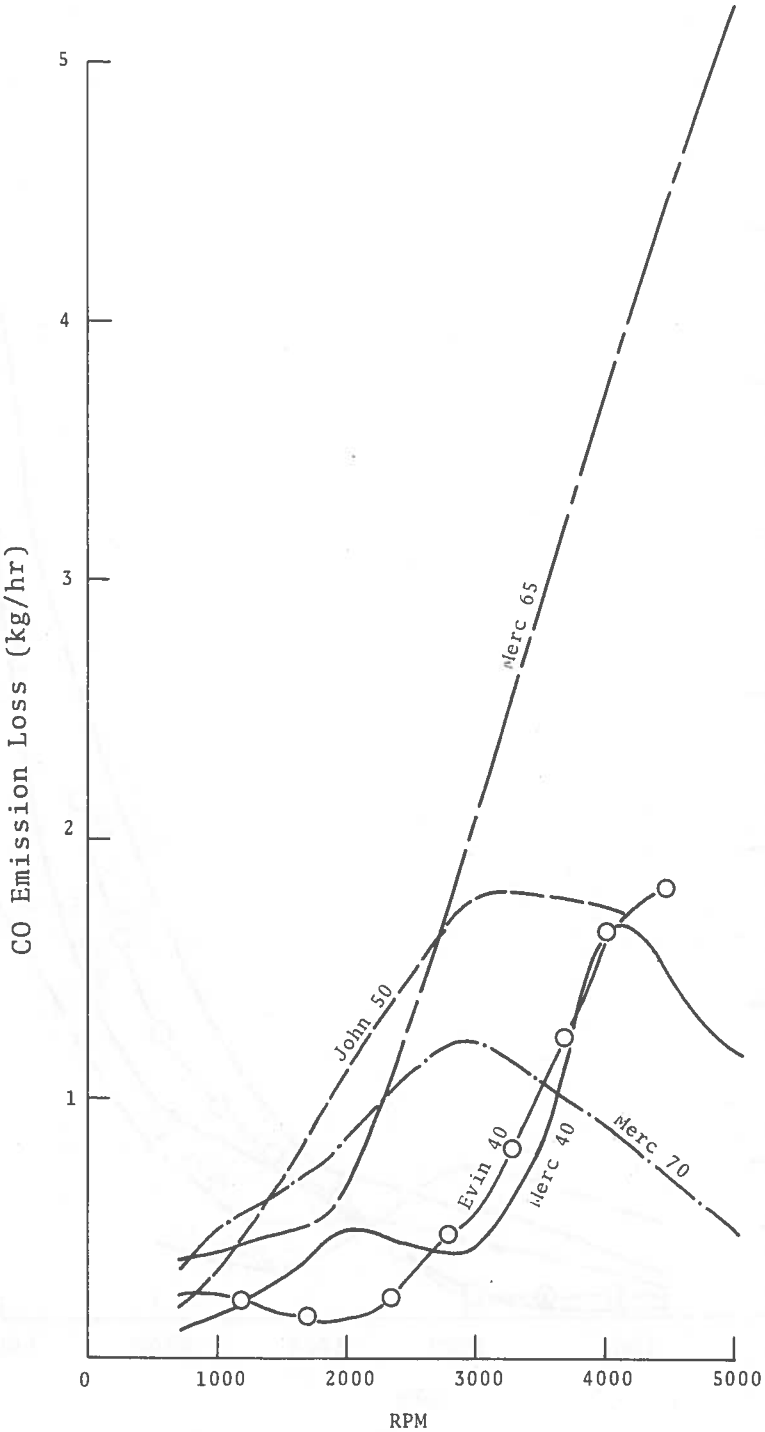


Figure 62. CO Emission Losses in Water

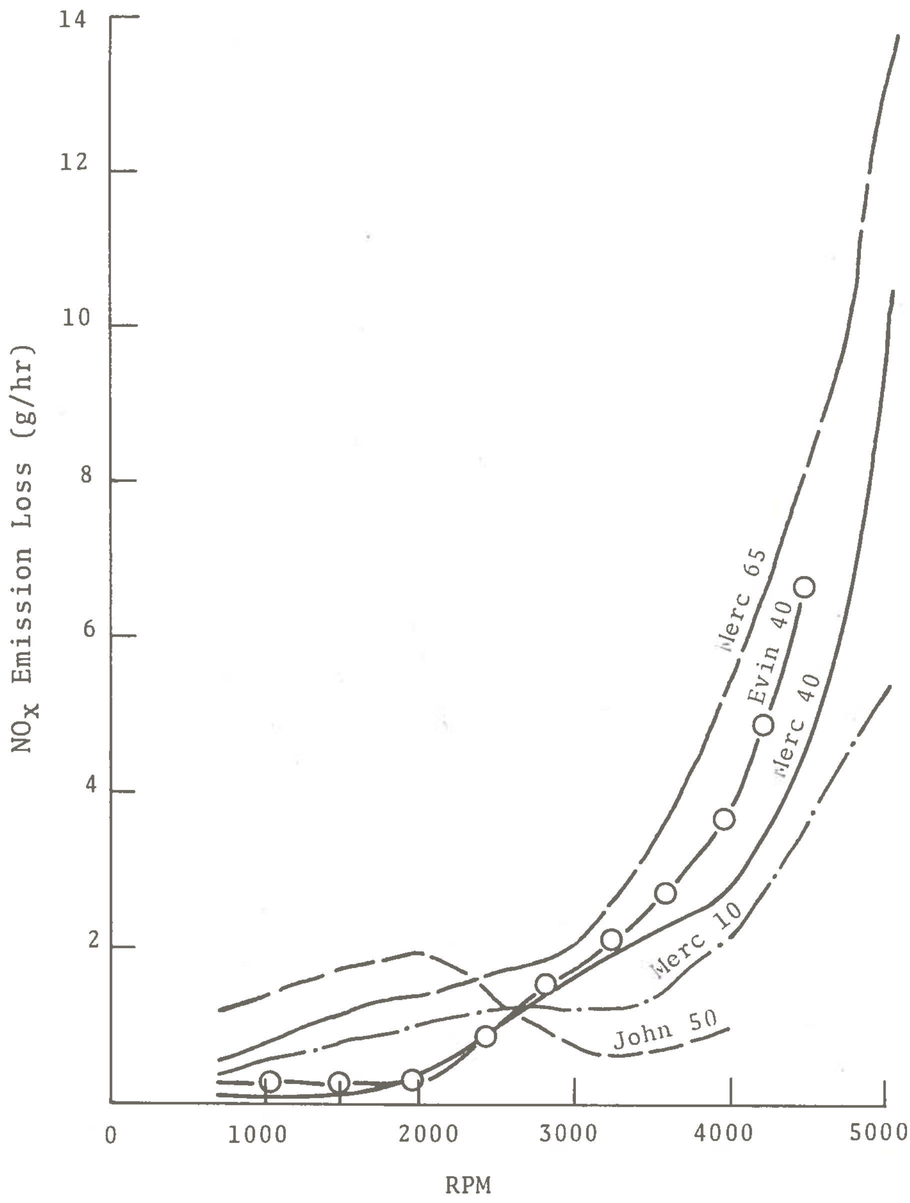


Figure 63. NO_x Emission Losses in Water

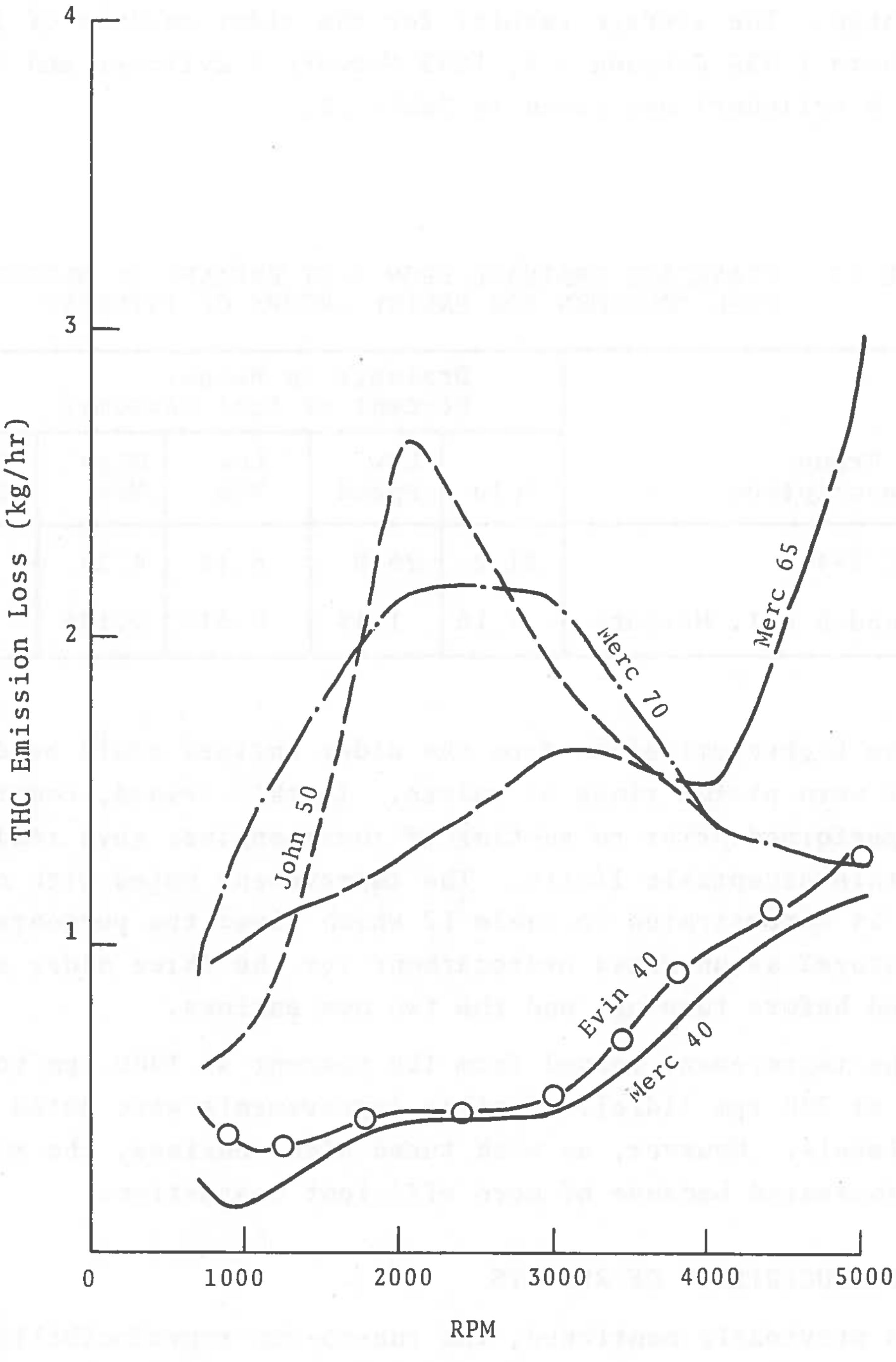


Figure 64. THC Emission Losses in Water

A recent study conducted by SWRI for EPA (Reference 4) gave the crankcase drainage from older test engines in weight percent of fuel consumed by groups according to manufacturer and horsepower range. The average results for the older engines of interest here (1959 Johnson V-4, 1965 Mercury 4 cylinder and 1962 Mercury 6 cylinder) are given in Table 11.

TABLE 11. CRANKCASE DRAINAGE FROM TEST ENGINES IN WEIGHT OF FUEL CONSUMED FOR ENGINE GROUPS OF INTEREST

Group Description	Drainage in Weight Percent of Fuel Consumed				
	Idle	Low Speed	Low Mid	High Mid	High Speed
OMC V-4	31.2	26.9	6.48	4.39	4.84
4 and 6 cyl. Mercury	2.16	1.48	0.512	0.126	0.053

The higher emissions from the older engines could be due, in part, to worn piston rings or valves. In this regard, compression checks performed prior to testing of these engines gave readings well within acceptable limits. The improvement noted with new engines is demonstrated in Table 12 which gives the percentage of fuel measured as unburned hydrocarbons for the three older engines (averaged before tune-up) and the two new engines.

The improvement ranged from 110 percent at 3000 rpm to 23 percent at 700 rpm (idle). Similar improvements were noted in the CO levels. However, as with tuned older engines, the NO_x levels increased because of more efficient combustion.

4.5 REPRODUCIBILITY OF RESULTS

As previously mentioned, the run-to-run reproducibility did vary from engine to engine. The 1962 Mercury results had the best run-to-run reproducibility and the 1959 Johnson had the worst

TABLE 12. AVERAGE PERCENTAGE OF UNBURNED FUEL

RPM	Old Engines	New Engines	% Improvement
700	54.0	44.0	23.0
1000	50.5	35.5	42.0
2000	51.6	27.5	87.0
3000	41.0	19.5	110.0
4000	29.5	20.0	47.5
5000	27.0	21.5	25.5

reproducibility. The statistics presented in Section 3.4 on the 1974 Evinrude were typical and proved to be much better than expected. These tests seem to indicate confidence in the results reported herein.

5. EMISSIONS IMPACT

It should be emphasized that any emissions impact based on the results of this study are estimates only and are based on assumptions where hard data is lacking.

In order to evaluate the emissions impact of the Coast Guard outboard engines, the following information was needed:

1. Outboard emissions as a function of speed and load;
2. Numbers and sizes of engines in the Coast Guard fleet;
3. Coast Guard outboard engine operating modes, i.e., time vs. speed and load;
4. Total operating hours.

Using the data presented in the preceding chapters on outboard emissions, a systematic approach was developed to evaluate the Coast Guard outboard fleet emissions.

5.1 OUTBOARD ENGINES IN CG FLEET

Through conversations with district personnel, it was determined that each district has approximately 100 outboard engines. These engines vary in size from 10 hp to 85 hp. The population mix as a function of hp is approximated as follows:

HP	% of Engines at Given HP
10	10
20	15
40	10
65	60
>65	5

The widely used 65 hp engine powers the popular Boston Whaler. Assuming the same distribution in each district, about 1000 outboard engines exist in the Coast Guard fleet.

5.2 OUTBOARD ENGINE OPERATING MODES

Data was developed by OMC (as reported in Reference 1) on outboard engine usage that shows percent of time in rpm intervals as a function of engine size, boat length, and type (runabout, cruiser, fishing, etc.). The data for cruiser/runabouts with 50 hp engines will be used in this study as they more closely approximate the average Coast Guard usage and engine size. These data were further regrouped for this study into rpm intervals that correspond to those of the engines tested here. These results are given below:

RPM	% of Time in Mode
idle	12
1000	12
2000	17
3000	12
4000	36
5000	5
5500	6

These percentages, expressed in decimal form, are used to develop time-weighted emissions and power for Coast Guard outboard engines.

5.3 EMISSIONS IMPACT CALCULATIONS

Table 13 gives the weighted emissions for each engine tested as a function of rpm and load. In the case of the older engines, these weighted emissions are after tune-up. Using these weighted emission factors, the composite emissions for each engine over this cycle can be found by summing as given in Table 14. This table gives the emissions in grams per hour if the engine was operated for the percent of time in the rpm modes listed in the previous section.

Composite test cycle hp ratings are obtained by summing the hp vs. rpm weighted test modes. For greater than 65 hp, the 70 hp engine was used. As with the emissions, the hp at each rpm are

TABLE 13. TIME-WEIGHTED EMISSION FACTORS FOR TEST ENGINES

	1959 Johnson (50 hp)		
RPM	CO (g/hr)	NO_x (g/hr)	THC (g/hr)
idle	342	.312	366
1000	540	.36	384
2000	119	.76	1198
3000	1200	1.03	738
4000	2736	6.66	2088
5500	382	2.00	279

	1964 Mercury (65 hp)		
RPM	CO (g/hr)	NO_x (g/hr)	THC (g/hr)
idle	84	.12	186
1000	90	.14	214
2000	224	.42	382
3000	594	.54	324
4000	2394	4.32	1170
5500	600	1.80	270

	1962 Mercury (70 hp)		
RPM	CO (g/hr)	NO_x (g/hr)	THC (g/hr)
idle	144	.10	204
1000	240	.132	276
2000	748	.42	637
3000	960	.54	456
4000	3420	3.80	1098
5000	630	1.05	185
5500	780	2.55	300

	1974 Evinrude (40 hp)		
RPM	CO (g/hr)	NO_x (g/hr)	THC (g/hr)
idle	108	.50	108
1000	114	.72	91.2
2000	119	.29	161
3000	210	.74	129
4000	2070	4.00	702
5000	312	1.00	125
5500	-	-	-

	1972 Mercury (40 hp)		
RPM	CO (g/hr)	NO_x (g/hr)	THC (g/hr)
idle	60	.24	54
1000	66	.24	36
2000	246	.14	127
3000	150	.46	90
4000	1656	2.0	522
5000	210	1.04	102.5
5500	-	-	-

TABLE 14. COMPOSITE TEST CYCLE EMISSIONS*

Engine	CO (g/hr)	NO_x (g/hr)	THC (g/hr)
1959 Johnson 50 hp	5319	11.1	5053
1964 Mercury 65 hp	4447	8.7	2771
1962 Mercury 70 hp	6922	8.58	3156
1974 Evinrude 40 hp	2903	6.8	1316
1972 Mercury 40 hp	2388	3.9	931

*Engines operated at idle, 1000, 2000, 3000, 4000, 5000, 5500 rpm.

multiplied by the percentage of time in each mode and summed to obtain a composite cycle hp. The results are:

Engine	Composite Cycle HP
10 hp	3.68
20 hp	7.36
40 hp	16.6
65 hp	22.1
>65 hp	21.3

For those categories not tested, the hp was calculated from the equation that relates speed and power:

$$P = K\ S^{2.5}$$

A composite brake specific mass emission rate was developed for the test engines by dividing the composite mass emission rates in g/hr given in Table 14 by the composite hp above. The results are given in Table 15.

It is interesting to note the fairly good agreement in test results by engine age group. In light of, and to simplify the preceding calculations, the old and new engine composite-cycle brake specific emissions are averaged and the results given in Table 16.

TABLE 15. BRAKE SPECIFIC MASS EMISSION RATES - COMPOSITE

Engine	CO (g/bhp/hr)	NO_x (g/bhp/hr)	THC (g/bhp/hr)
1959 Johnson 50 hp	238.2	0.5	226.3
1964 Mercury 65 hp	201.3	0.4	125.5
1962 Mercury 70 hp	325.0	0.4	148.2
1974 Evinrude 40 hp	168.3	0.4	76.3
1972 Mercury 40 hp	162.2	0.26	63.2

TABLE 16. AVERAGE BRAKE SPECIFIC COMPOSITE MASS EMISSIONS

	CO (g/bph/hr)	NO_x (g/bph/hr)	THC (g/bhp/hr)
Old Engines	254.70	.43	166.0
New Engines	165.25	.33	69.8

This again points out the improvement evident with newer engines. Further conversations with district personnel indicate that approximately 50 percent of the outboard engines in the fleet may be classified as "old". It was further concluded that the typical outboard engine in the Coast Guard fleet is operated for about 100 hours per year.

The total yearly emissions per typical district for each class of outboards (assuming 50 percent old and 50 percent new) can be calculated by:

(Brake Spec. Emis. g/bhp/hr (Table 15)) x (composite cycle hp) x (hrs/yr(100)) = Total yearly emissions (g/yr)

The average yearly emissions per district are given in Table 17.

The yearly emissions for the rest of the Coast Guard cutters and boats for each district and the fleet totals are compared to the outboard engine emissions in Table 18. When compared to the other cutter and boat emissions estimated for the First District, OE's represent 75 percent of the CO emissions, .09 percent of the NO_x emissions, and 77.5 percent of the THC emissions.

On a fleet basis OE's represent 15 percent of the CO, .008 percent of the NO_x, and 29 percent of the THC.

TABLE 17. AVERAGE YEARLY EMISSIONS PER TYPICAL DISTRICT FOR USCG OE ENGINE CATEGORIES

	OLD			NEW		
HP	CO (g/yr)	NO_x (g/yr)	THC (g/yr)	CO (g/yr)	NO_x (g/yr)	THC (g/yr)
10 hp	$4.7x10^5$	$7.9x10^2$	$3.05x10^5$	$3.04x10^5$	$6.1x10^2$	$1.3x10^5$
20 hp	$1.4x10^6$	$2.4x10^3$	$9.2x10^5$	$9.12x10^5$	$1.8x10^3$	$3.8x10^5$
30 hp	$2.1x10^6$	$3.5x10^3$	$1.4x10^6$	$1.3x10^3$	$2.7x10^3$	$5.7x10^5$
65 hp	$1.7x10^7$	$1.9x10^4$	$1.1x10^7$	$1.1x10^7$	$2.2x10^4$	$4.6x10^6$
>65 hp	$1.35x10^4$	$2.3x10^3$	$8.8x10^5$	$8.8x10^5$	$1.8x10^3$	$3.7x10^5$
Totals	$2.3x10^7$	$2.8x10^4$	$1.45x10^7$	$1.44x10^7$	$2.89x10^4$	$6.05x10^6$

TABLE 18. YEARLY EMISSIONS FOR USCG FLEET AND OUTBOARDS

FIRST DISTRICT EMISSIONS					
Vessels	OE's	Vessels	OE's	Vessels	OE's
CO (lbs/yr)		NO_x (lbs/yr)		THC (lbs/yr)	
$2.8x10^4$	$8.3x10^4$	$1.3x10^5$	$1.2x10^3$	$1.3x10^4$	$4.5x10^4$
FLEET TOTAL					
Vessels	OE's	Vessels	OE's	Vessels	OE's
CO (lbs/yr)		NO_x (lbs/yr)		THC (lbs/yr)	
$5.5x10^6$	$.83x10^6$	$1.45x10^7$	$.12x10^4$	$1.08x10^6$	$.45x10^6$
OVERALL TOTAL					
Cutters and OE's					
CO (lbs/yr)		NO_x (lbs/yr)		THC (lbs/yr)	
$6.33x10^6$		$1.45x10^7$		$1.53x10^6$	

6. CONCLUSIONS

Based on the results of this study, the following conclusions can be drawn:

- The two-stroke cycle outboard engine emits high quantities of carbon monoxide (CO) and hydrocarbons (HC).

- The approximately 1000 outboard engines in use by the Coast Guard are responsible for a substantial portion of the CO and THC in the Coast Guard fleet emissions.

- On a national or regional basis, Coast Guard outboard engines are an insignificant contributor of CO, NO_x, and THC when compared to that emitted by the over 8 million outboards used in the pleasure fleet, other marine sources, and mobile sources in general.

- Periodic maintenance in the form of tune-ups should be performed on the Coast Guard's outboard engines to conserve fuel and minimize emissions. In this regard the Mercury service manual states: "An engine tune-up is a service to put the maximum capability of economy, power and performance back into the engine and, at the same time, assure the operator of a complete check and more lasting results in efficiency and trouble-free operation".

Each year, with the improved power and performance of the modern outboard engine, tune-ups have become increasingly important. Today, this increase in power and performance has meant higher compression ratios and new and improved electrical systems among other advances in design.

- Older engines should be replaced with more efficient, newer models.

7. REFERENCES

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4. Charles T. Hare and Karl J. Springer, "Crankcase Drainage from In-Service Outboard Engines," Southwest Research Institute, San Antonio TX, Report EPA-670/2-74-092, December 1974.