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CRANKCASE DRAINAGE FROM IN-SERVICE OUTBOARD MOTORS

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CRANKCASE DRAINAGE FROM IN-SERVICE OUTBOARD MOTORS

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

The research reported here provides data on which estimates of total outboard motor crankcase drainage could be based. Data available prior to this study were inadequate for such estimates. The estimates are needed as background information for other EPA studies dealing with effects of outboard motors on the aquatic environment.

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ABSTRACT

Crankcase drainage from 35 outboard motors was measured during normal operation on two lakes in the San Antonio area. The motors included a variety of sizes and brand names, and they were tested under prolonged constant-speed conditions as well as cyclic speed conditions designed to simulate user operation in the field. Four engines of the same group were also tested with a drainage intercepting and recirculating device.

Drainage was measured by both mass and volume, and results were also computed in mass per unit time (g/hr) and percentage of fuel consumed by weight and by volume. Analysis of some fuel samples was conducted by gas chromatograph, including a few in which drainage was mixed with fuel by the recirculating device mentioned above. Photographic documentation of the test engines, the drainage systems, and test/measurement techniques was also obtained.

Based on measurements obtained during this study and estimations on the current outboard motor population, a range for the national total crankcase drainage emissions was estimated. It was also found that the major causes of variation in drainage rates were engine type, engine operating speed, and differences from one engine to another of the same type (or a similar type).

This report was submitted in partial fulfillment of Research Contract EHS 70-108, under the sponsorship of the Environmental Protection Agency, Office of Research and Development.

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ACKNOWLEDGEMENTS

This project was conducted at Southwest Research Institute by Charles T. Hare, under the management of Karl J. Springer, Director of the Department of Emissions Research.

Support of the project by the Environmental Protection Agency and the technical assistance of Dr. Thomas J. Padden, Project Officer, are greatly appreciated.

The experimental work was conducted on the Institute grounds and at nearby Medina Lake. Field work was performed by Nathan Reeh, John T. Jack, Joyce Winfield, Del Ray O'Neill, and Jimmie Chessher.

SECTION I

CONCLUSIONS AND RECOMMENDATIONS

1. Outboard motors with overboard drains have not been produced since 1971. The following conclusions are applicable only to drain type outboard motors produced prior to 1971. All outboard motors manufactured after 1971 are drainless so total drainage emitted will decrease slowly as older engines are retired from service. Outboards are very rugged, however, so it is expected that drained engines will be operating in significant numbers for many years to come.

2. Crankcase drainage rates varied considerably from one engine type to another, and also between identical or similar engines.

3. Drainage rates generally varied inversely with engine speed, and drainage as a percentage of fuel used also generally varied inversely with engine speed.

4. Ignition tuning did not appear to affect drainage rate significantly, but carburetor adjustments seemed to have a measurable effect.

5. As classified by crankcase drainage characteristics, the total engine population is (statistically) two separate populations, an Outboard Marine Corporation (OMC) group and a "non-OMC" group.

6. Based on the major assumptions: (1) that the engines tested in this study are a valid sample of the total outboard population, (2) that outboards operate 50 hours per year, (3) that outboards spend equal time in the five steady-state sampling conditions employed for this study, (4) that OMC and non-OMC populations are statistically separate, (5) that 55 percent of engines in operation are of OMC manufacture, and (6) that fuel density is 0.87 times drainage density; the following can be deduced for drained engines:

   (a) Drained engines consume about 600 million gallons of fuel per year.

   (b) The estimated OMC population average crankcase drainage is between 3.19 and 7.51 percent by weight of fuel consumed.

(c) The estimated non-OMC population average crankcase drainage is between 0 and 2.76 percent of fuel by weight.

(d) The estimated average drainage of the total population of drained engines is between 1.8 and 5.4 percent of fuel consumption by weight.

(e) The OMC population emits between 9.2 and 22 million gallons of drainage per year; the non-OMC population emits between 0 and 6.5 million gallons; and total drainage is between 9.2 and 28 million gallons per year.

(f) At speeds of 1500 rpm and lower, it can be stated with 95 percent confidence that the OMC population average crankcase drainage is between 11 and 23 percent of fuel consumed by weight. The corresponding limits for the non-OMC population are 1.4 and 4.6 percent.

(g) At speeds of 1500 rpm and lower, it is estimated that drainage from the OMC population totals between 6.4 and 13 million gallons; that drainage from the non-OMC population is between 0.5 and 1.8 million gallons; and that one-half to three-fourths of total annual drainage occurs at engine speeds of 1500 rpm and lower.

7. For the "non-OMC" engines tested in this study,* the range at high speed was from amounts too small to measure (under 0.1 percent) to over 8 percent, with a mean of about 0.8 percent. Only one engine had drainage at high speed which was over 0.2 percent, so the median (0.066 percent) probably characterizes the central tendency better than the mean. The range of drainage at idle (in weight percent of fuel consumed) was from under 0.3 percent to almost 20 percent, with an arithmetic mean of about 7 percent.

8. For the OMC engines in this study,* the range of drainage at high speed was from under 0.3 percent to about 6 percent, with a mean of about 2 per-

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*The results of this study are not pertinent to outboard motors produced since 1971.

cent. The range of drainage at idle (expressed as weight percent of fuel consumed) was from under 1 percent to over 42 percent. One half the engines had drainage of 21 percent or greater, with an arithmetic mean of about 20 percent.

9. In assessing potential for environmental impact on a body of water, the overall percentage based on the assumed usage cycle is not adequate. Some bodies of water, for instance, may be populated almost exclusively by non-OMC engines; while others may have the opposite situation. A given body of water may also be subject to something other than the "average" drainage because engines are run mostly at low speeds in that area (places such as inlets, marinas, and troll-fishing locations).

10. At least one device is available commercially which will intercept drainage, and a model which recycled the intercepted drainage was given a limited test. Analysis of fuel mixed with drainage indicates that it contains a higher percentage of heavier fuel components than fresh gasoline does. The tests were not extensive enough to determine whether or not the drainage recycling process causes any change in engine performance.

11. In order to make the best usage of the drainage data, it would be necessary that a boat usage survey be conducted to supplant the usage assumptions used in this report. Such a survey should be designed to gather time-in-mode data on a variety of boats (perhaps 1000 or more) distributed all over the country, as well as total operating time data.

12. Drainage data acquired during this study and similar information from other research efforts are probably adequate for estimating drainage from engines in service. No further testing specifically for drainage quantity is recommended.

13. More extensive evaluations of commercially-available drainage interception/recirculation devices could be made.

SECTION II

INTRODUCTION

The purpose of this research project was to determine the amount of crankcase drainage emissions from a number of outboard motors and to estimate the national total of such emissions. Thirty-five motors were tested. They were drawn from the population in service in the San Antonio area, and care was taken to obtain data during conditions as representative of user operation as possible. Motors tested were all water-cooled and represented all the major manufacturers. Testing was conducted in or near San Antonio, with the smaller motors being operated on the contractor's small lake and the larger ones on Medina Lake (about 30 miles west of San Antonio).

Two-stroke cycle outboard engines (which do not have oil injection systems) rely on oil pre-mixed with their fuel supplies for lubrication. Proper lubrication of moving parts requires that some condensation of gasoline/oil vapors must occur in the crankcase, and the liquids condensing tend to accumulate after some period of time unless the entrance to one of the transfer passages is in the lowest part of the crankcase. An accumulation of these liquid materials can cause poor performance or a condition called "hydraulic lock", in which the engine would be inoperative and might be damaged (hydraulic lock prevents the pistons from moving)., Some new engine designs incorporate the low transfer passage design, and the remaining new engines use an internal recirculating system to collect the accumulated liquids and introduce them directly into the cylinder to be vaporized and burned. This project, however, concerns itself primarily with engines manufactured between the early 1950's and mid-1971 which disposed of liquid drainage by allowing it to mix with the exhaust stream and be released into the water.

Figure 1 is a simplified schematic diagram of a 2-stroke gasoline engine (reed-valve type) which shows how the crankcase drainage systems of the older engines operate. Figure 1a shows the engine during the compression stroke, and at the same time the crankcase is in its intake phase, with the inlet reed valve open and the drain check valve closed. Figure 1b shows the engine during the power stroke, and the crankcase is in its compression phase, with the inlet reed valve closed and the drain check valve open. Since both the inlet reed valve and the drainage check valve are pressure-actuated, flow into and out of the crankcase depends on crankcase pressure. When crankcase pressure is low (during compression stroke), mixture is inducted into the crankcase and drainage can collect over the check valve. When crankcase pressure is high

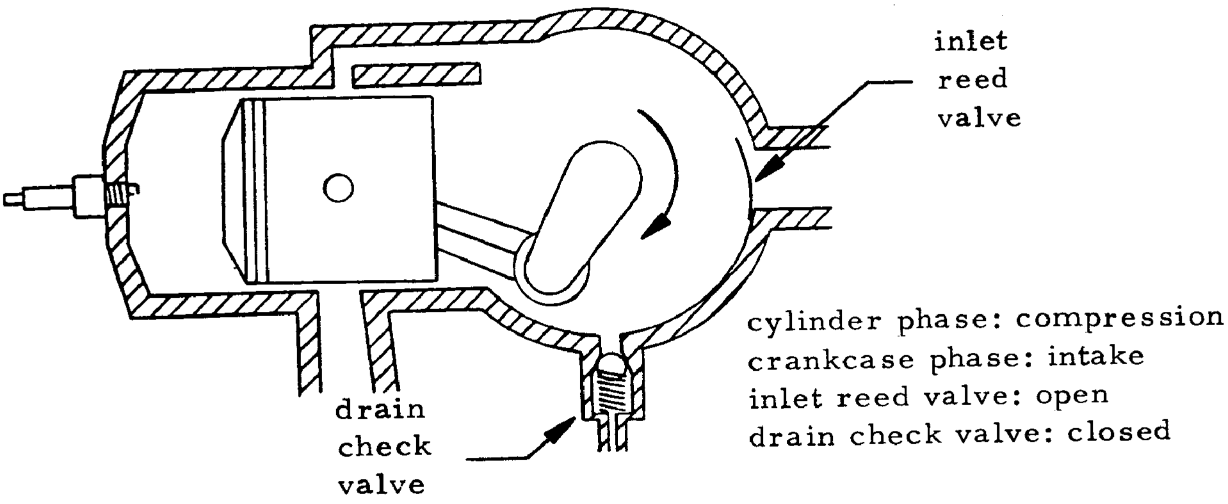

Figure 1a

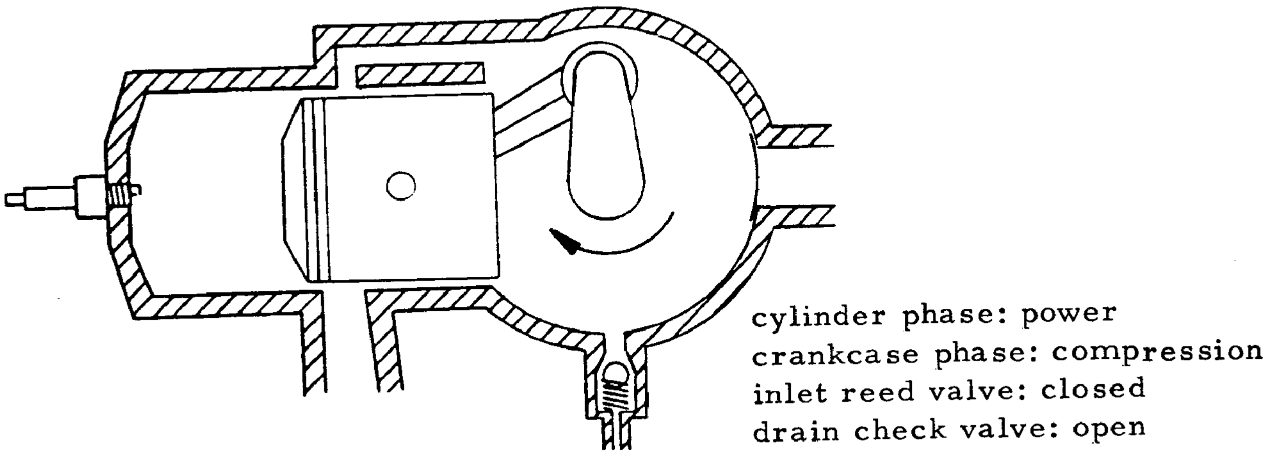

Figure 1b

Figure 1. Simplified schematic section of a 2-stroke cycle gasoline engine

(power stroke), liquid and some gaseous materials are forced from the crankcase through the check valve. The inlet reed valve is relatively large with a typical diameter of 1 inch (25mm); and it requires only a small pressure differential to be opened. The check valve is smaller, however, with a typical diameter of 0.1 inch (2.5mm); and it requires a rather high pressure differential for opening. These valve characteristics mean that relatively large gas/vapor flows can be accomodated by the inlet reed valve but that only smaller(by volume) flows of liquid (plus some gases and vapors) can pass through the drainage check valve.

Design of drainage systems and their physical layouts varied considerably over the range of engine types tested. The Mercury and Chyrsler engines which were tested incorporated small check valves for drainage control, and the OMC engines used small leaf (or reed) valves. Location and diameter of the drainage passages also varied from engine to engine. Most of the OMC systems utilized internal passages with external access to the check valves themselves for inspection or cleaning. Chrysler and Mercury systems were generally a mixture of internal passages and external lines. The design of the systems used on the test engines will be documented in detail in a later section of this report.

This study was not the first work on drainage emissions from outboards, so it is appropriate to review at this point materials available in the literature(1-6)* and try to resolve some of the apparent lack of agreement in the previous work (data tabulated in Table 1).

References 1 through 6 contain 48 usable drainage data points on 17 outboard motors, while other reports and articles available (7-18) contain only restatements of data published elsewhere or information which does not bear directly on drainage quantity. The usable data from other sources are shown in Table 1, and it should be noted that three of the engines were tested by engine manufacturers (total of 18 data points) and the remainder (14 engines, 30 data points) by other agencies or groups. Drainage data for Chrysler and Mercury outboards listed in Table 1 agree very well with the experimental results of this study. Data on drainage from OMC engines (Johnson, Evinrude, and Gale) shown in Table 1 generally indicate higher values than the engines tested in this study. No information is available to assess the reasons for these differences.

The data in Table 1 exhibit very strong variation with engine speed and

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*Superscript numbers in parentheses refer to list of References at end of report.

Table 1. CRANKCASE DRAINAGE DATA FROM OTHER INVESTIGATIONS

Data ref.	Engine	Rpm	Drain %
1	1965 Chrys. 9.2 hp	800	20.
		1000	19.
		1250	21.
		2000	18.
		2500	14.
		3000	9.
		4000	5.
		4800	3.
1	1965 - 50 hp	800	14.
		1000	25.
		1250	15.
		1500	14.
		3000	0.5
		5000	0.5
1	1961 Evin. 60 hp	1000	55.6
		2000	53.8
		4000	7.7
1	1963 Johns. 5 hp	1500	1.6
1	1965 Johns. 33 hp	1500	31.2
1	1964 Johns. 64 hp	1500	54.7
1	1959 Evin. 50 hp	1500	53.1
1	1961 Gale 40 hp	1500	31.2
1	1967 Merc. 95 hp	600	2.3
1	1966 Merc. 50 hp	600	1.6
1	1959 Merc. 40 hp	600	1.6
1	1968 Merc. 125 hp	600	2.0
2	Johns. 33 hp	1000	40.8
		2000	39.9
		3000	28.3
3	Merc 50 hp	750	4.5
		1000	4.0
		2000	0.6
		3000	0.04
		4000	0.03
4	1971 Chrys 35 hp	750	24.0
	(avg. 2 runs)	1000	20.6
		2000	3.6
		3000	0.4
		4000	0.4
5	Chrys. 35 hp	1000	11.0
	(avg. 2 runs)	1500	8.2
		2000	3.4
		3000	0.7
		4000	1.0
6	Evin. 33 hp	1000	28.3
	(avg. 2 runs)	2000	6.6
		2500	7.4
		3000	3.0

from engine to engine, and this variation has previously caused doubts as to validity of the whole range of data. Although no specific analysis of the Table 1 data has been made, the existence of variation due to the same parameters has been documented by this study. This finding lends more credibility to previously-obtained data, although documentation of many previous tests is not adequate for assessing the validity of specific data points. If the data discussed in this section say anything strongly, it is that simplistic generalizations (such as using one data point to project a nationwide total for drainage emissions) about drainage rates must be regarded with suspicion.

SECTION III

EXPERIMENTAL METHODS AND EQUIPMENT

Design of the test procedure used in this project required simulation of user operation of outboards, development of sample acquisition and handling methods, and attention to calculation methods and presentation of data. It was decided that the tests would include steady-state motor operation at idle, maximum or rated speed, and several intermediate speeds, as well as cyclic motor operation. It was also decided that tests would be conducted both before and after tuning the engine to determine the effect of tuning on drainage. Data acquired during steady-state operation proved useful in showing the effect of engine speed on drainage rate, while those obtained during cyclic operation probably related more closely to drainage which occurred from engines used to gather time-in-mode data. Data obtained during various steady-state conditions can also be weighted according to time-in-mode data to calculate cycle composite drainage.

The only hard data available on outboard motor usage are in the form of survey data compiled by Outboard Marine Corporation(19, 20). The first part of this survey was conducted in 1971(19) and the second part in 1972(20). The second part of the data was received by SwRI in September of 1972, after some of the outboards had already been tested under the subject program. When the second part of the data was received, the operating schedule for the outboard testing was consequently revised somewhat. The engines tested using the first operating schedule included Numbers 2 through 9, and all the others (1, 10 through 35) were tested using the second operating schedule. Engine Number 1 was retested late in the program (after use of the second operating schedule had begun) because it was discovered that the crankcase relief valve cover plate gasket had been defective, causing erroneous results for engine 1 as first operated.

The motor usage survey data as supplied by OMC are given in Table 2, including both parts mentioned above. To avoid using a number of engine test conditions corresponding to the intervals used in the OMC data (11 intervals), it was considered advantageous to regroup the percentages on larger intervals. Table 3 shows averages of the OMC data (both the first part alone and the whole survey) according to engine size categories, and five test conditions were finally decided upon. Two of the test conditions had already been chosen, namely, normal idle and maximum rpm (or manufacturer's rated rpm, if lower). The other three conditions were to fall between idle and maximum rpm, and were to be as representative of

Table 2. OUTBOARD MOTOR USAGE SURVEY DATA FROM OMC(19, 20)

		Boat			Percent operating time in rpm interval (rpm in hundreds)										
Unit	Size, hp	Length, ft	Type	Test hours	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60
A[a]	125	17	Runabout	16.72	34	12	3	5	6	14	12	10	3	1	--[b]
B[a]	100	17	Runabout	11.56	32	20	7	3	1	7	13	11	4	2	--[b]
C[a]	100	18	Runabout	48.94	24	14	4	2	1	4	11	33	5	2	--[b]
D[a]	55 (Dual)	23	Cruiser	24.30	4	19	15	5	2	2	8	37	8	0	--[b]
E	50	16	Runabout	14.24	13	19	5	10	5	10	7	10	5	11	5✓
F	50 (Dual)	20	Cruiser	13.56	5	12	11	5	5	12	24	22	2	1	1
G	40 (Dual)	16	Runabout	14.44	3	13	12	7	3	13	13	19	12	5	--[b]
H[a]	9.5	16	Fishing	21.56	6	13	10	6	6	9	8	19	18	5	--[b]
I	9.5	14	Fishing	14.24	12	11	7	9	3	9	5	25	15	4	--[b]
J	9.5	14	Fishing	10.24	4	11	12	19	11	25	15	3	0	--[b]	--[b]
K	9.5	14	Fishing	10.16	9	11	9	4	4	9	22	19	12	--[b]	--[b]
	Total all motors			199.96											

[a] Motors included in first part of survey, hours total 123.08.

[b] Motor would not attain this rpm due to boat load, propeller, etc.

Table 3a. OUTBOARD MOTOR USAGE SURVEY DATA AVERAGED OVER MOTOR SIZE RANGES, FIRST PART OF SURVEY ONLY(19)

Rpm range	Percent operating time in rpm range Engines 50 hp and over	9.5 hp Engine
500-1000	21.9	5.9
1000-1500	15.7	12.6
1500-2000	6.8	9.8
2000-2500	3.3	6.4
2500-3000	2.2	5.8
3000-3500	5.7	8.9
3500-4000	10.6	8.3
4000-4500	27.4	18.9
4500-5000	5.4	18.0
5000-5500	1.0	5.2
5500-6000	0.0	0.4
TOTALS	100.1	100.2

Table 3b. OUTBOARD MOTOR USAGE SURVEY DATA AVERAGED OVER MOTOR SIZE RANGES, ENTIRE SURVEY(20)

	Percent operating time in rpm range for engine size(s)			
Rpm range	100 hp and over	50-55 hp	40 hp	9.5 hp
500-1000	30	7	3	8
1000-1500	15	17	13	12
1500-2000	5	10	12	10
2000-2500	3	7	7	10
2500-3000	3	4	3	6
3000-3500	8	8	13	13
3500-4000	12	13	13	12
4000-4500	18	23	19	16
4500-5000	4	5	12	11
5000-5500	2	4	5	2
5500-6000	0	2	0	0
TOTALS	100	100	100	100

normal operating conditions as possible.

Looking at the data in Table 3a, it was assumed that operation under 1000 rpm represented idle and that operation over 5000 rpm represented full speed. The remainder of the speed range was divided into three parts for large engines: 1000-2000 rpm, 2000-3500 rpm, and 3500-5000 rpm. These ranges were characterized by their medians (1500, 2750, and 4250 rpm, respectively); and the medians were termed "low speed", "low mid-speed", and "high mid-speed", respectively. For small engines, the ranges were 1000-2000, 2000-4000, and 4000-5000 rpm. These ranges were also characterized by their medians (1500, 3000, and 4500 rpm, respectively), and the terms in which these speeds were stated were the same as for the larger engines. Low speed was considered to be typical of trolling and maneuvering in small boats and typical of maneuvering in larger boats. The mid-speeds were considered typical of maneuvering and cruising for small boats and typical of a transition speed (not much used) and cruising or skiing for larger boats. Table 4a shows the operating conditions and time-based weighting factors developed from data given in Table 3a. Note that data for the 9.5 hp engine were used to derive the conditions for the "Under 20 hp" category and that the average of data for the 9.5 hp engines and the "50 hp and over" group was used for engines in the "20-45 hp" category (in lieu of applicable data).

The data in Table 3b were treated very much like those in Table 3a to arrive at the second set of operating conditions. Examining the survey data as a whole, however, indicated that changes should be made as shown in Table 4b. The major changes from 4a to 4b are in the greater amount of time at "high speed" and "low mid-speed", and the smaller time at "high mid-speed". This change in the distribution of operating time came about as a result of the additional data collected in the second part of the usage survey. Data for the "100 hp and Over" column of Table 3b were used to develop data in the corresponding column of Table 4b, and the percentages in the last column of Table 3b were used to develop the figures in the "Under 20 hp" column of Table 4b. Data in the "50-55 hp" column of Table 3b were used to compute the percentages in the "50-95 hp" column of Table 4b, and the averages of data in the "50-55 hp" and "9.5 hp" columns of Table 3b were used to derive values in the "20-45 hp" column of Table 4b. Data from the "40 hp" column of Table 3b were not used, but their use would have tended only to reduce "idle" percentage and increase "high speed" percentage slightly in the "20-45 hp" category. The time percentages were used to derive 20-minute test "cycles" having nine modes (modes 1 and 9 at "idle", 2 and 8 at "low speed", 3 and 7 at "low mid-speed", 4 and 6 at "high mid-speed", and 5 at "high speed"), with the total length of time at each

Table 4a. TEST CONDITIONS DERIVED FROM FIRST PART OF OMC USAGE SURVEY DATA--USED FOR TEST ENGINES 2-9

Condition	Engines 50 hp and over		Engines 20-45 hp		Engines under 20 hp	
	Speeds	% of time	Speeds	% of time	Speeds	% of time
Idle	Idle	22	Idle	14	Idle	6
Low speed	1500	22	1500	22	1500	22
Low mid.	2750	11	3000	16	3000	21
High mid.	4250	44	4500	44	4500	45
High speed	----[a]	1	----[a]	4	----[a]	6

[a]Middle of rated speed range for engines 20 hp and over, top of rated speed range for engines under 20 hp.

Table 4b. TEST CONDITIONS DERIVED FROM ENTIRE OMC USAGE SURVEY DATA--USED FOR TEST ENGINES 1, 10-35

Condition	Speed	Percent of operating time at condition for engine category			
		100 hp and over	50-95 hp	20-45 hp	Under 20 hp
Idle	Idle	30	7	8	8
Low speed	1500	20	27	24	22
Low mid.	2750	14	19	24	29
High mid.	4000	30	36	32	28
High speed	----[a]	6	11	12	13

[a]Middle of rated speed range for engines 20 hp and over, top of rated speed range for engines under 20 hp.

condition defined by the percentages given in Table 4 and the 20-minute cycle length. These cycles did not necessarily represent average motor operation in the field, but they were based on the limited amount of usage data currently available.

Some variations in the designated speeds occurred for several engines due to differences in idle speeds, differences in maximum speeds which could be obtained, and so forth. In order to document the actual speeds at which each engine was run, Table 5 includes these data as well as model year, manufacturer, and rated horsepower for each motor tested. An explanation is in order on engines designated 15 and 15a. Engine 15 performed well in testing, but after run 12 it appeared to overheat. The problem was a burned head gasket, which was the first visible sign of block erosion between the cylinder liners on the right bank. The entire powerhead was replaced with a new unit for a 1968 Evinrude 65 hp motor; and due to this extensive repair, the rebuilt unit was considered as a separate engine for analysis purposes. Engines 24 and 27 were converted from drainless to drained configuration for test purposes, because at that time, difficulty was being experienced in obtaining small motors for tests. Engines 30 and 31 were converted from drainless to drained configuration prior to their receipt by SwRI. The representativeness of these converted engines in describing drainage from the population of engines in the field will be discussed in a later section of this report.

One of the goals of this project was to represent the major brands and models of engines in use as well as possible, and the data presented in Table 6 give some indication of the degree to which this goal was achieved. The group of test engines is probably weighted somewhat more heavily toward OMC motors than is the case with the national motor population, but this lack of agreement reflects the availability situation in the San

Table 6. DISTRIBUTION OF TEST ENGINES
BY MANUFACTURER AND SIZE

Hp range	Chrysler[a]	Mercury	OMC	Subtotals
0-18	1	2	12	15
20-44.9	1	0	6	7
45 & up	4	5	5[b]	14
Subtotals	6	7	23	Total 36

[a] Includes two similar "Sea King" engines marketed by Montgomery Ward.
[b] Includes engines 15 and 15a as separate engines.

Table 5. OUTBOARD MOTOR SPECIFICATIONS AND OPERATING SPEEDS

Test engine		Engine rpm in cycle modes (speeds)				
No.	Description	1 & 9 (Idle)	2 & 8 (Low)	3 & 7 (Low mid.)	4 & 5 (High mid.)	5 (High)
1	1965 Johnson 9.5 hp	1000	1500	2750	4000	4700
2	1960 Evinrude 18 hp	800	↑	3000	4000	4500
3	1966 Johnson 33 hp	700		3000	4500	4800
4	1965 Mercury 65 hp	650		2750	4250	4250
5	1954 Evinrude 15 hp	1000		3000	4000	4500
6	1965 Sea King 50 hp	900		2750	4250	4750
7	1959 Mercury 45 hp	1000		2750	4250	5000
8	1968 Johnson 40 hp	800		2750	4300	4300
9	1961 Johnson 40 hp	1000		3000	4500	5000
10	1967 Evinrude 80 hp	900		2750	4000	5000
11	1971 Chrysler 55 hp	900		↑	↑	4600
12	1953 Johnson 10 hp	1000				4500
13	1967 Johnson 33 hp	800				4500/4800[b]
14	1968 Mercury 95 hp	900				5000
15	1963 Gale 60 hp	1000				5000
15A[c]	1968 Evinrude 65 hp	1000				5000
16	1964 Mercury 65 hp	1000				4400/5000[b]
17	1963 Mercury 85 hp	900				5000
18	1968 Evinrude 85 hp	800				5000
19	1971 Chrysler 45 hp	800			↓	4450
20	1968 Sea King 45 hp	900			4000	4750
21	1953 Johnson 25 hp	850			3500/3700[b]	3500/3700[b]
22	1960 Johnson 75 hp	1000			4000	4200/5000[b]
23	1970 Chrysler 5 hp	900			4000	4400
24[a]	1972 Evinrude 9.5 hp	1000			4000	4600
25	1971 Johnson 9.5 hp	900			3900	3900
26	1970 Johnson 6 hp	1100			3800/3900[b]	3800/3900[b]
27[a]	1972 Johnson 9.5 hp	1000			4000	4000
28	1971 Evinrude 9.5 hp	1000			↑	4500
29	1967 Mercury 6 hp	1000				5400
30[a]	1971 Mercury 9.8 hp	700				4600/4500[b]
31[a]	1972 Evinrude 18 hp	1000				5000
32	1971 Chrysler 35 hp	1000				4750
33	1966 Johnson 40 hp	1000				4500
34	1971 Evinrude 9.5 hp	900	↓	↓	↓	4250
35	1964 Evinrude 9.5 hp	900	1500	2750	4000	4350

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[a] Originally drainless engine converted to drained configuration for tests.

[b] Maximum rpm before/after tuning.

[c] Rebuilt version of Engine 15 (powerhead).

Antonio area. The only survey data on engine population by manufacturer which seems to be available currently(18) shows percentages by manufacturer for a sample of owners at Lake George, New York. These data show 56 percent for OMC, 25 percent for Mercury, and 15 percent for Chrysler, as compared to the sample tested in this program with 17 percent Chrysler, 19 percent Mercury, and 64 percent OMC. With proper weighting of numbers of engines sampled, representing an assumed population distribution of motors should not be a problem. Another part of the distribution problem, of course, is that 2-cylinder Mercury engines (drained type) cannot be sampled without rather extensive engine disassembly and modification. Engine 29 was purchased by SwRI so these steps could be performed without asking too much of a private owner, and the modification will be detailed in Section IV.

Aside from engine parts modified to permit collection of drainage samples (which will be discussed in Section IV), very few major items of equipment were needed for this project. Several of the necessary equipment items are shown in Figures 2 and 3. Figure 2 shows the insulated container used for holding a sample bottle in the water bath while samples were being taken (the sample bottles used were of 125 ml, 250 ml, or 500 ml capacity depending on the engine and condition being sampled). Figure 3 shows several pre-weighed fuel cans on the floor of the boat and the tachometer on the seat between the operator's knees. This tachometer operated by integrating pulses from one spark plug, which were coupled to the meter circuitry inductively through a cable flexible enough to pass between the motor housing and the rubber weatherstrip on the top motor cover. Other necessary items were stopwatches for timing the runs, scales for weighing fuel cans before and after runs to determine fuel usage, and a laboratory scale for weighing sample bottles before and after sample collection.

The tuning which was performed on the test engines consisted of new spark plugs in all cases, check and replacement of points where necessary, check and adjustment of timing if necessary, and check and adjustment of carburetor jet settings where necessary. Consequently, a substantial stock of spark plugs and other small parts was consumed during the course of the project. The other major items consumed were tubing used for sample lines, outboard motor oil, and gasoline. The oils were all "BIA Certified Service TC-W" with brand name corresponding to the engine under test, and they were mixed with fresh gasoline in concentrations as recommended by the engine manufacturers (see data sheets, Appendix A). The gasoline used was a leaded commercial regular grade ("Good Gulf"), stored in sealed 55-gallon drums, and was as uniform in specifications as possible to prevent variation in drainage due to fuel composition.

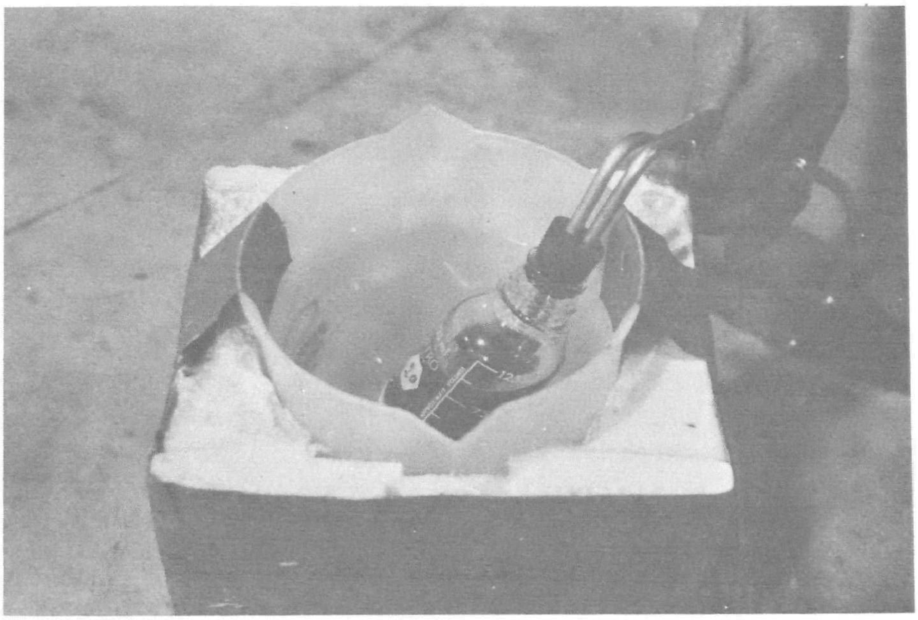

Figure 2. Insulated container for sample bottle and water bath used during tests

Figure 3. Engine undergoing drainage test, showing drainage tube, pre-weighed fuel cans, and tachometer (on seat)

SECTION IV

ACQUISITION OF DRAINAGE DATA IN THE FIELD

Crankcase drainage data were acquired on the test engines during operation at one of two possible field locations. Most of the tests on small motors were conducted on a small pond located within the Institute grounds, as shown in Figures 4 and 5. This pond was too small to operate craft powered by engines over 10 hp, so the tests of larger motors were conducted at Medina Lake, about 30 miles west of San Antonio. The lower end of Medina Lake is shown in Figure 6.

Most of the experimental work performed on this project occurred between August 1 and December 31, 1972 and between October 15 and December 15, 1973. The work proceeded rather slowly at first in 1972, while procedures were still being ironed out, but accelerated to the point at which three to four engines were being tested per week. Toward the end of both the 1972 and 1973 programs, work slowed again due to undesirable weather and difficulty in acquiring motors considered necessary to filling out the test group.

One of the challenges of the project was locating the external access points of various drainage systems, and modifying motor parts to permit acquisition of samples without changing the amounts of drainage the engines normally emitted. A schematic of a typical drain system is shown in Figure 7a. Some engines used check valves, while others used small reed valves; but the "one way" operation was essentially the same. Instead of a cover plate, several engines had an external line running from the check valve to the passage leading into the motor leg. Samples were acquired from these engines by disconnecting the line at one end and extending the line to the sample bottle, while extending a line from the other sample bottle tube back to the point where the original drain line had been disconnected. The sample bottle/water bath and a modified cover plate are shown schematically in Figure 7b. The vapor return line was employed on as many engines as possible to keep the pressure against which the drainage flowed as much like the real (unmodified) situation as possible, but vapors were simply vented to the atmosphere from the sample bottle for a few engines (24, 26, 27 and 29).

In total, nine distinct types of modifications were used to acquire drainage samples, beginning with a modification of the diamond-shaped OMC cover plate shown in Figures 8 through 10. Figure 8 shows the modified plate installed on Engine Number 1, Figure 9 shows the outside

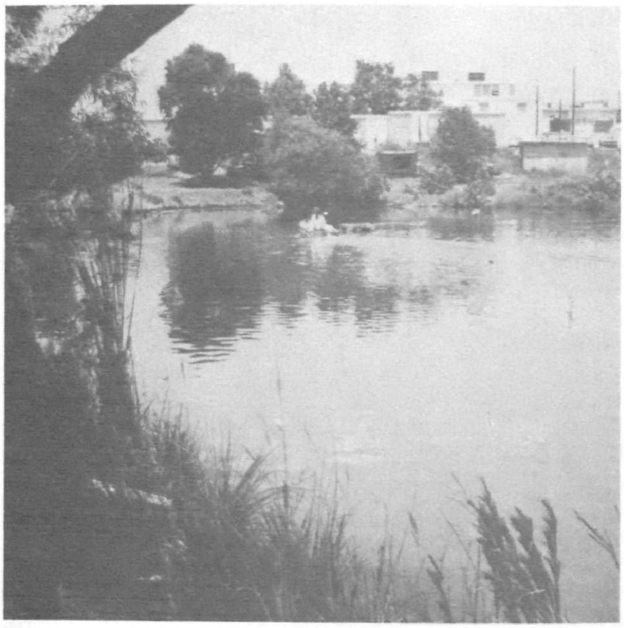

Figure 4. First view of Institute pond used for small motor tests

Figure 5. Second view of Institute pond used for small motor tests

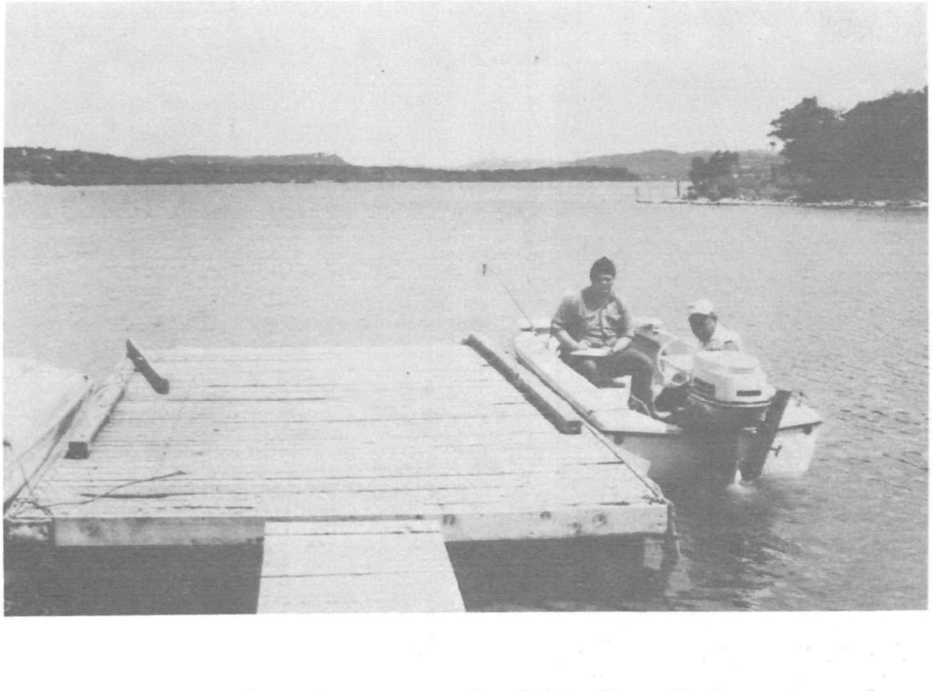

Figure 6. Lower end of Medina Lake viewed from private boat-launch area

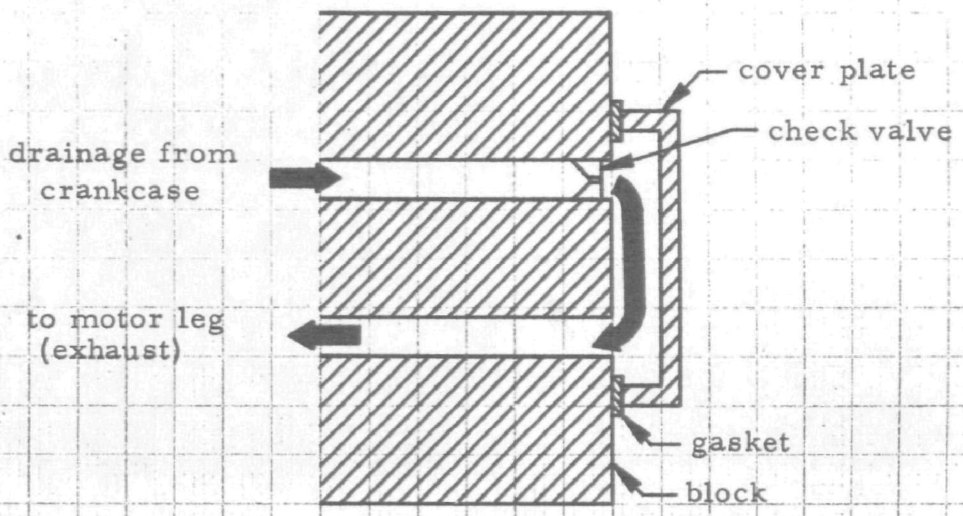

Figure 7a. Schematic section of typical drain system

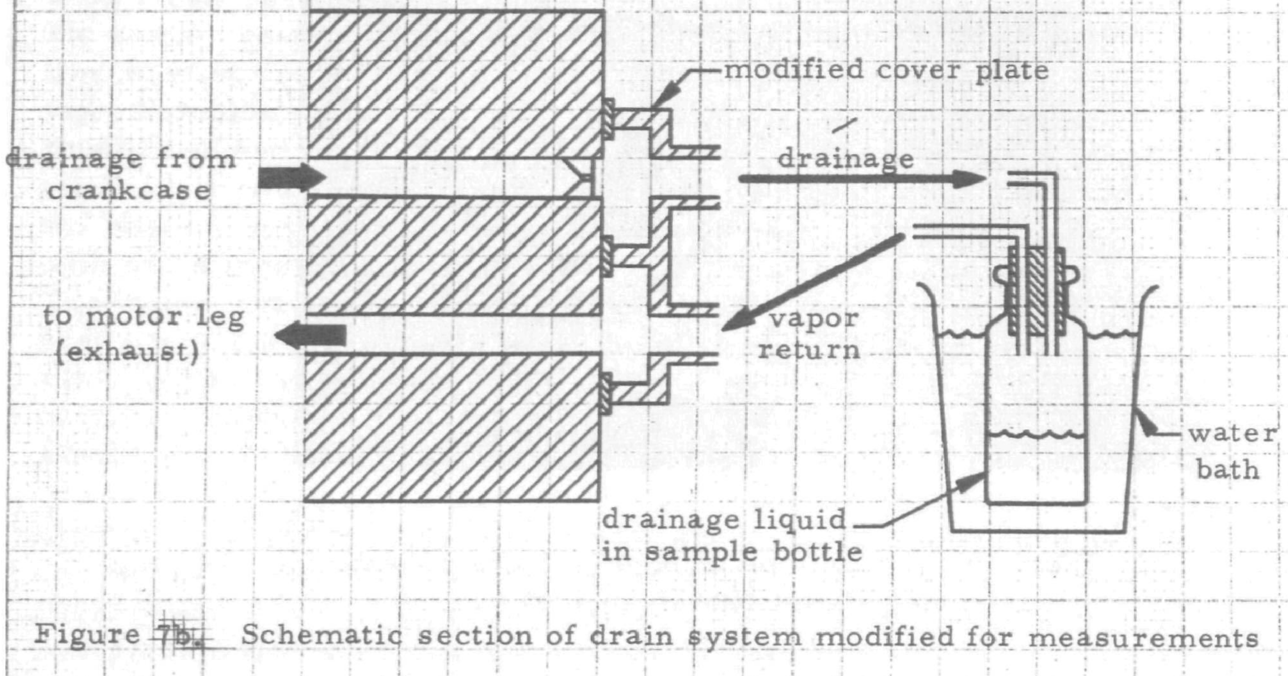

Figure 7b. Schematic section of drain system modified for measurements

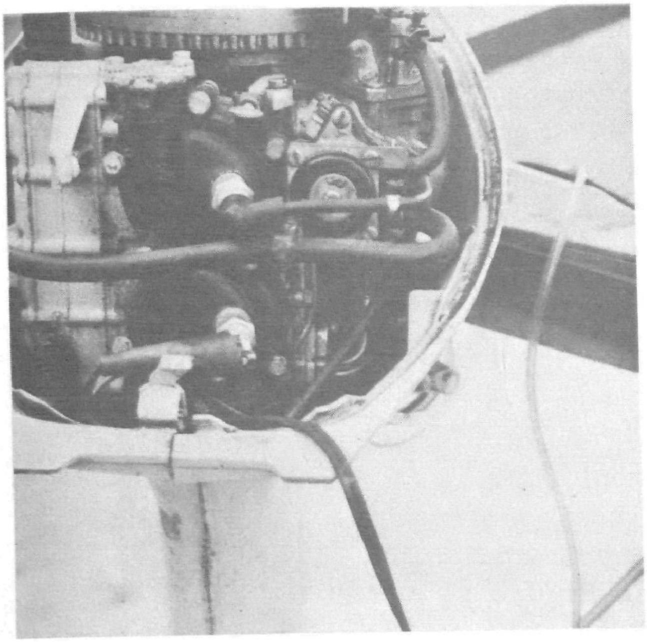

Figure 8. Installation of tachometer leads and special plate for re-routing of crankcase drainage, engine 1

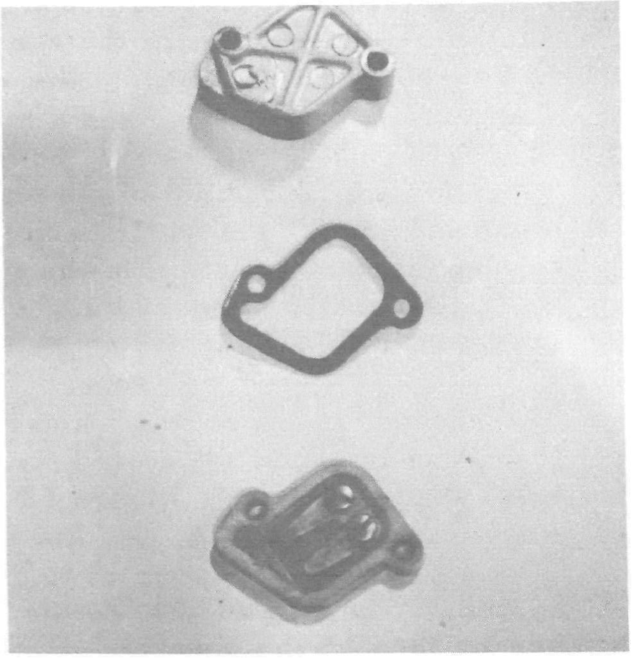

Figure 9. (Top to bottom) crankcase relief valve cover plate, gasket, and reed plate similar to those widely used on OMC engines

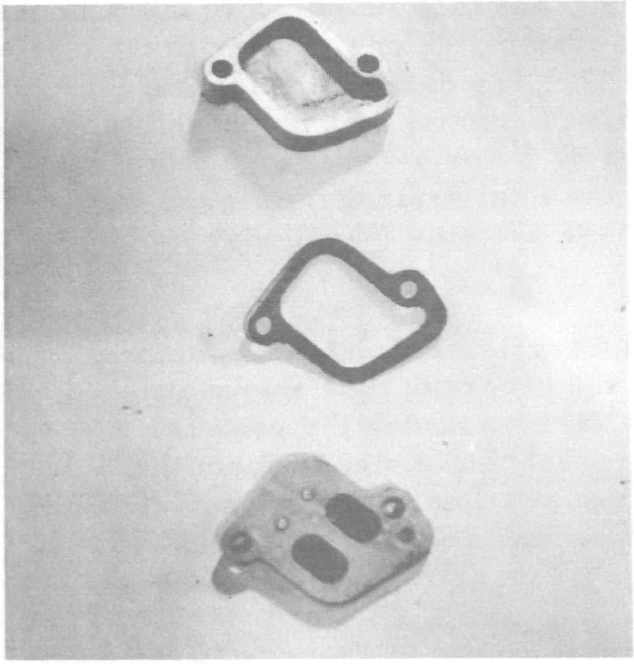

Figure 10. Inside faces of same parts shown in Figure 9

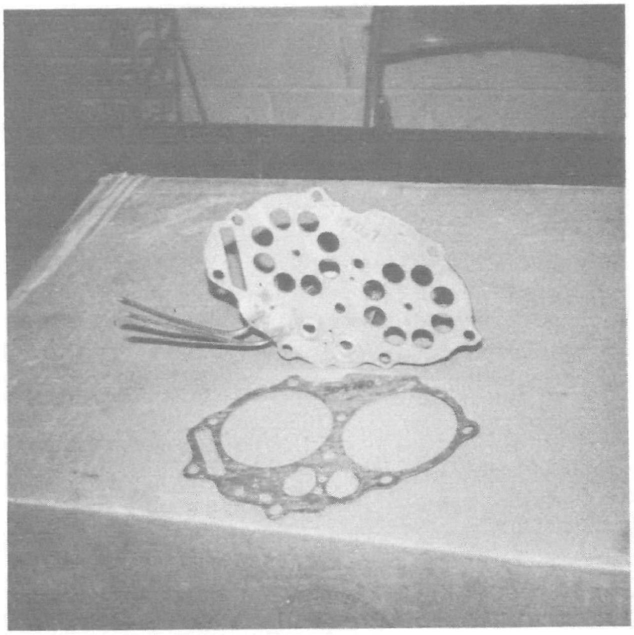

Figure 11. Modified reed plate used to extract drainage from OMC 15 hp and 18 hp motors (engines 2 and 5)

faces of the stock drainage reed plate and cover plate, and Figure 10 shows the inside faces of the same parts. The modified cover plate had a web added to separate the reed valves from the hole which leads down into the motor leg, and a modified gasket was made to seal this partition. In operation, both gaseous and liquid drainage components were routed out of the chamber covering the drainage reed valves to the sample bottle, and gaseous constituents were routed back to their normal outlet. This modified plate was used to collect drainage on Engines 1, 3, 8, 9, 12, 13, 21, 25, 28, 33, 34, and 35, which were OMC twins.

The second type of modification involved the modified reed plate shown in Figure 11, and it was used on Engines 2 and 5 (OMC 18 hp and 15 hp twins, respectively). Figure 12 shows the surface on which the modified plate was mounted, and the drainage channel was blocked between the tubes shown in Figure 11 to direct the drainage into the collection system. The tube further to the right in Figure 11 permitted gases to escape through the normal drain passage.

In modifying 4- and 6-cylinder Mercury engines, the external drainage line from the upper pair (or pairs, in the case of 6-cylinder engines) of cylinders was disconnected and extended to the sample collection system. Another line was attached at the point where the stock line was disconnected to serve as a return line for gases, and a typical installation is shown in Figure 13. The line leading from the fitting mounted on the engine block at center is the drainage line, and the one joined to the original neoprene tube is the return. This system, or one similar to it, was used for Engines 4, 7, 14, 16, and 17. The drainage point from the lower pair of cylinders on all these Mercury engines was inaccessible, so the measured drainage was multiplied by 2 (for 4-cylinder motors) or 1.5 (for 6-cylinder motors) to estimate the total drainage. Figure 14 shows a schematic of the Mercury drainage systems (6-cylinder motor shown).

The system required for the 35 to 55 hp Chrysler and Sea King motors is shown in Figure 15. In these cases, the neoprene tube shown at center was disconnected from the fitting directly under the rectifier stack and then extended as shown with transparent tubing to form the sample line. The gas return line is shown attached to the downstream fitting mentioned above. This modification was used on Engines 6, 11, 19, 20, and 32.

The modification made to OMC V-4 engines, shown in Figures 16 through 19, involved changes to the inlet manifold. The stock manifold and the reed block are shown in Figure 16, while Figures 17 and 18 show two

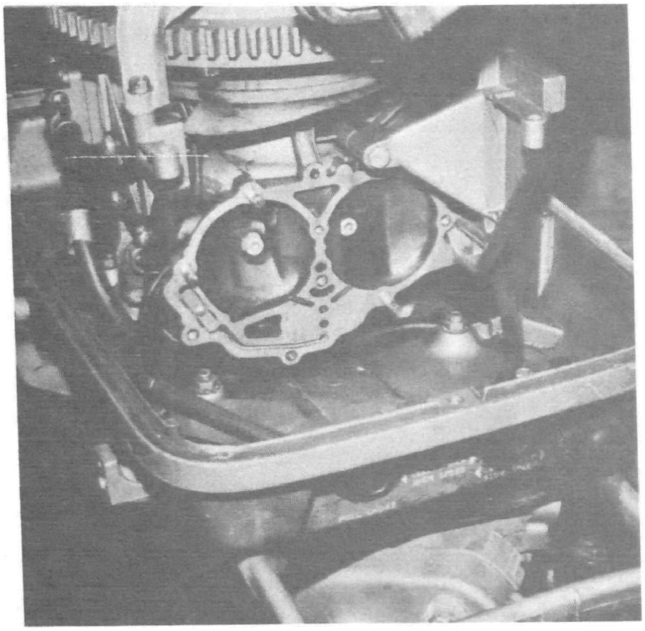

Figure 12. Front face of crankcase half, engine 2, showing normal crankcase drainage channel

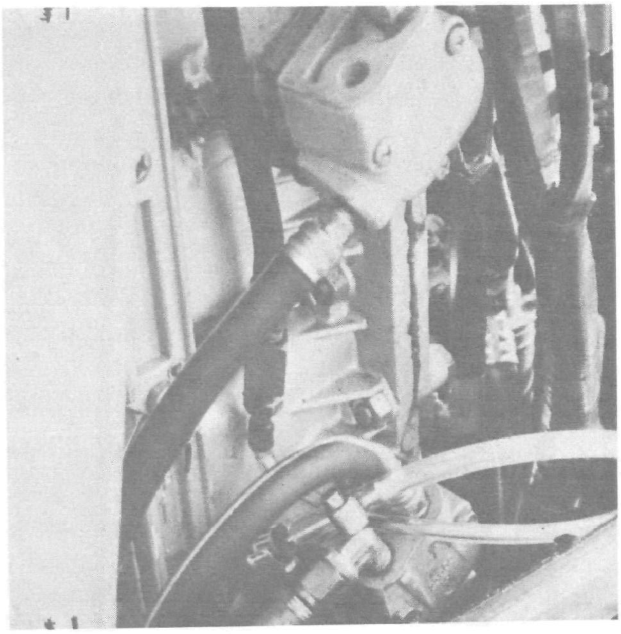

Figure 13. Drainage re-routing system typical of those used on 4- and 6-cylinder Mercury motors (engine 14 shown)

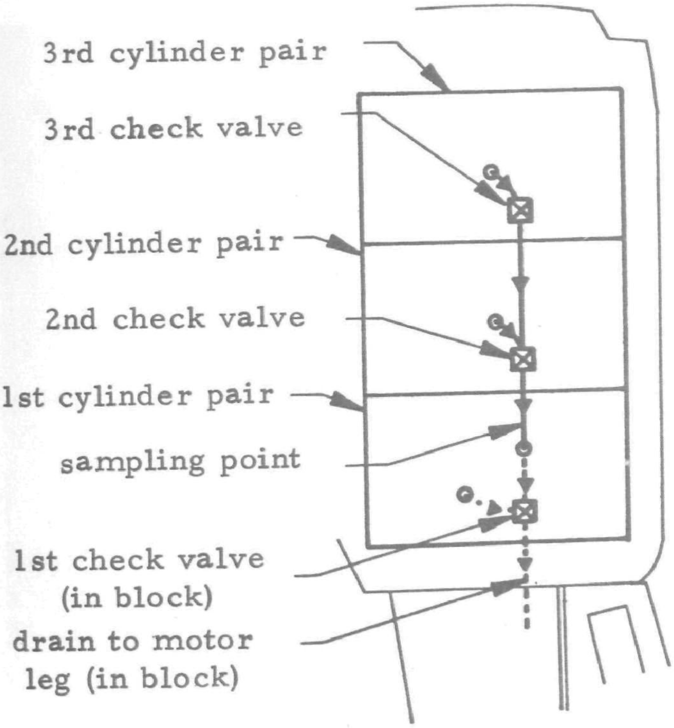

Figure 14. Schematic of drain system, Mercury 6-cylinder motor

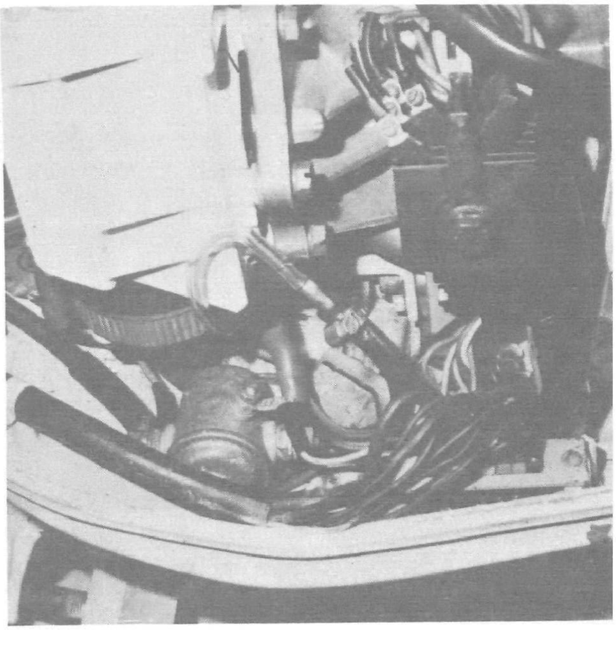

Figure 15. Crankcase drain tube for engine 6, plus (transparent) collection tube and gas return tube

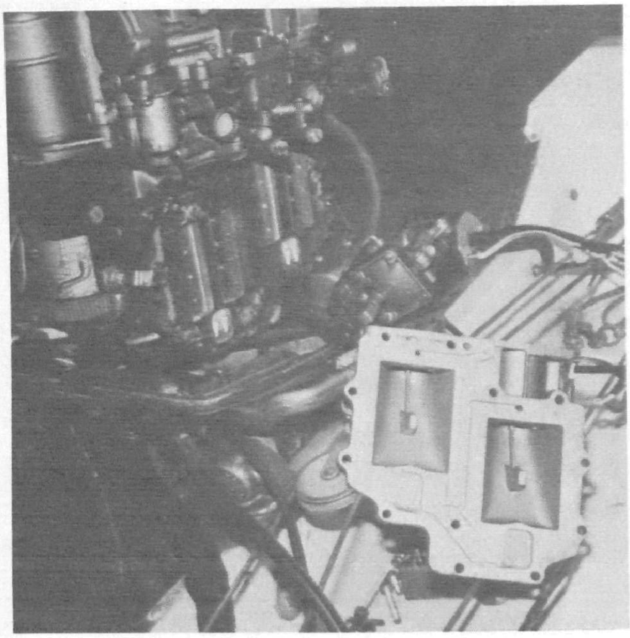

Figure 16. Engine 10 (OMC V-4) partially disassembled, showing drainage reed valves below ports in reed block (left) and stock inlet manifold (lower right)

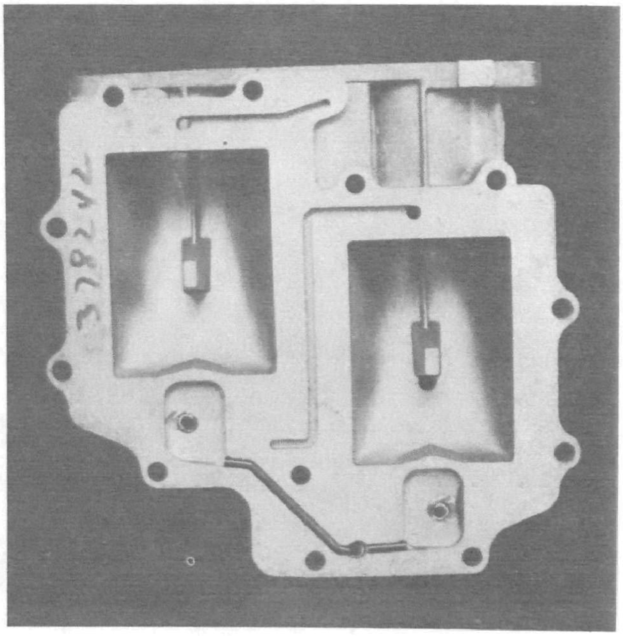

Figure 17. Modified OMC V-4 inlet manifold, showing blocked drain channel, two drain holes, and one return hole

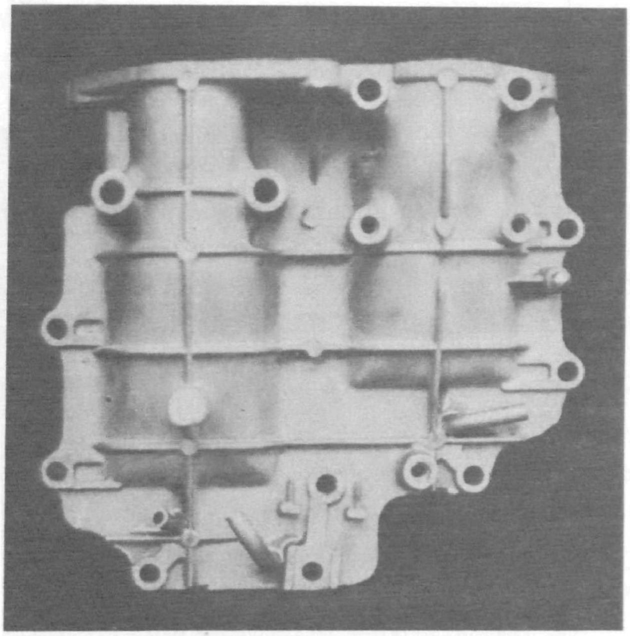

Figure 18. Outside of modified OMC V-4 inlet manifold, showing drain tubes (left and right), gas return tube (center), and blocked manifold pressure tap (appears white, left)

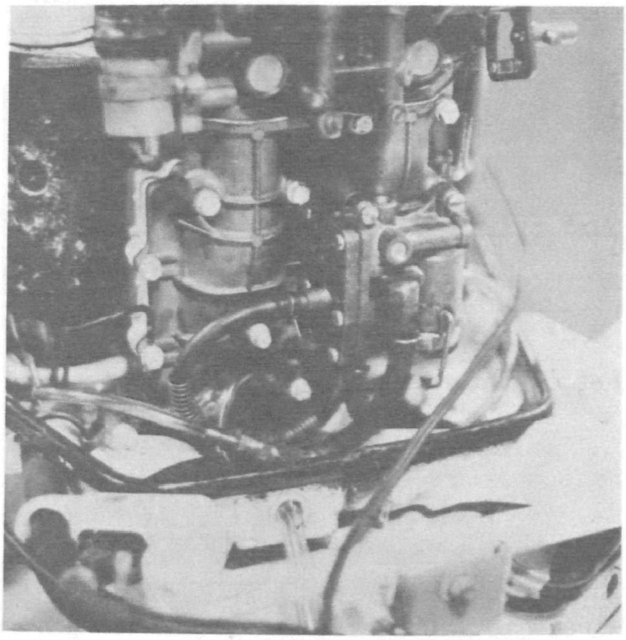

Figure 19. Modified inlet manifold installed on engine 10, showing routing of drain and return tubes (two drain tubes join at the tee just inside motor cover)

views of the revised manifold. The principle used here was again the blocking of normal drain passages, diverting drainage into the sample collecting system and permitting gases to escape through the return line and into the motor leg. Figure 19 shows the installation of the modified part as well as drainage and return lines. The modified V-4 inlet manifold was used for tests on Engines 10, 15, 15a, 18, and 22.

Another type of modification was required for Engine 23, the only small (under 20 hp) Chrysler motor tested. This engine used a system of two check valves (one per cylinder) mounted in the crankcase bleed valve cover plate as shown in Figure 20. Once again the normal drain channels were blocked to re-route sample through collection tubes to a tee, and then on to the sample bottle. The gas return line was installed downstream of the blocked channels, as usual. Figures 21 and 22 show mounting position for the plate and the installation of the modified part, respectively.

In order to test Engines 24 and 27 (1972 models), it was necessary to convert them to a drained configuration since they were origainlly drainless. These engines were tested only because no older engines of the same type could be located at the time (late 1972). As discussed in Section IV, the validity of converting drainless engines is somewhat in doubt. The method employed was to block the channels through which drainage was normally recycled as shown in Figure 23 and to install the modified inlet manifold shown in Figure 24 to permit acquisition of samples. Figure 25 shows the modified part installed, and it should be noted that both the lines are drain lines. The complexity of the manifold did not permit installation of a gas return line, so gaseous components of the drainage were simply vented to the atmosphere. Engines 30 and 31 were also originally drainless, and they had been modified for acquisition of samples prior to their receipt by SwRI.

The modification required for Engine 25, an OMC 6 hp model, again was in the inlet manifold as shown in Figures 26 through 28. Figure 26 shows the exterior of the manifold with the single drain tube, and Figure 27 shows the same part from the inside. Due to the proximity of the drainage reed valves to the internal (downstream) drain passage, it was impractical to use a gas return line on this engine; and gases (not liquid) were vented to the atmosphere from the sample bottle. Figure 28 shows the front face of the inlet reed plate of Engine 25, the surface on which the inlet manifold was mounted.

The last engine tested in 1972 was Number 29, a Mercury 6 hp unit; and it required more extensive disassembly before drainage could be measured than any other test engine. Figure 29 shows the bottom surface of

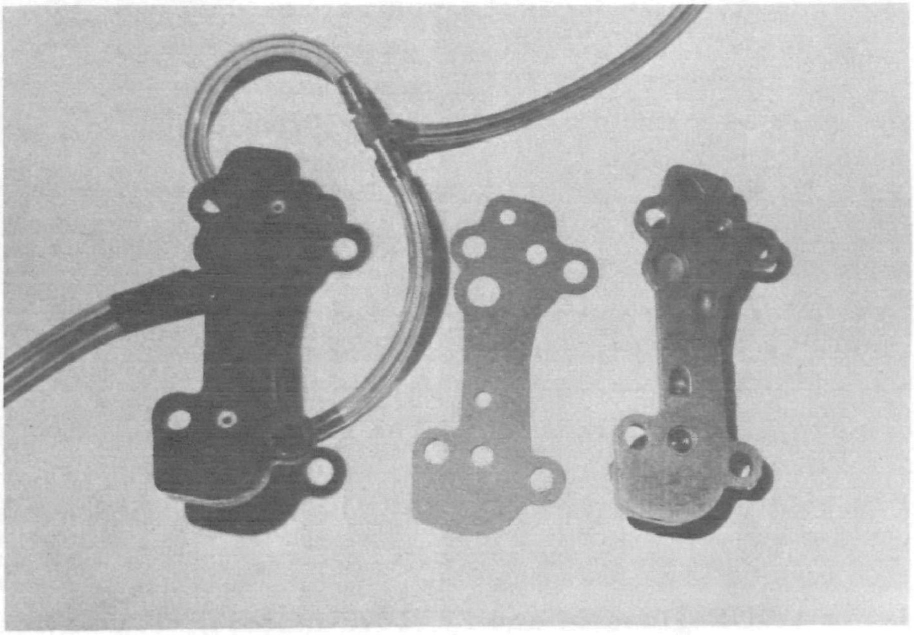

Figure 20. Modified and stock crankcase bleed valve plates for a 1970 Chrysler 5 hp outboard

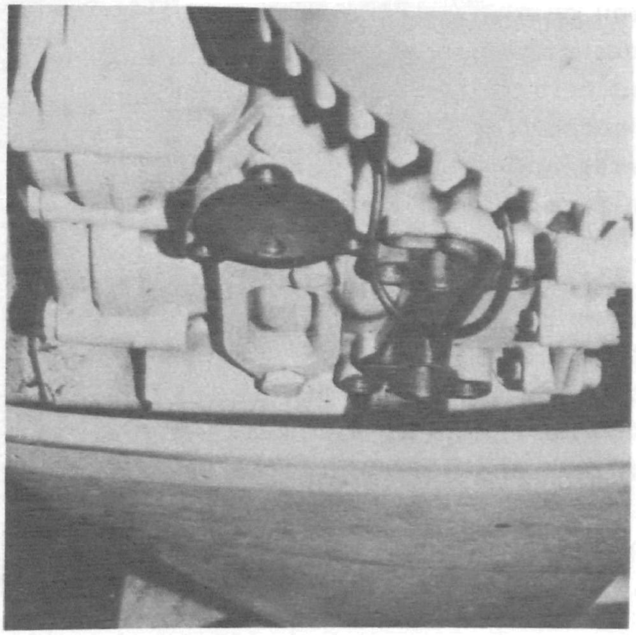

Figure 21. Mounting position for crankcase bleed valve plate on a Chrysler 5 hp outboard

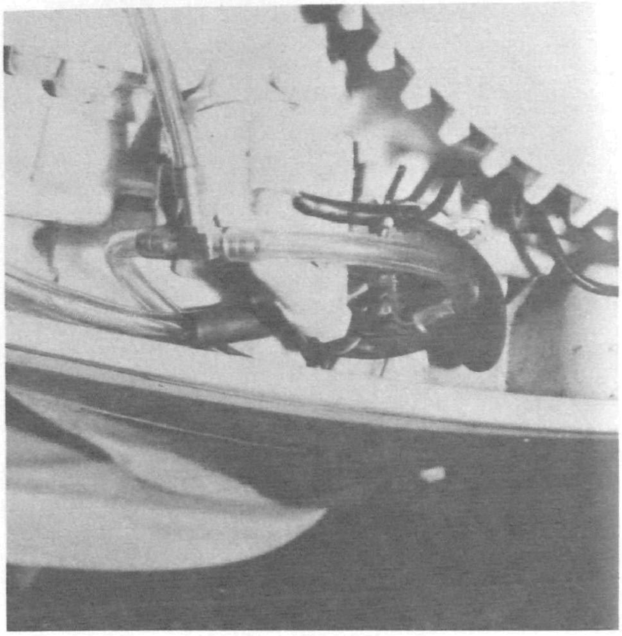

Figure 22. Modified crankcase bleed valve plate installed on a Chrysler 5 hp outboard

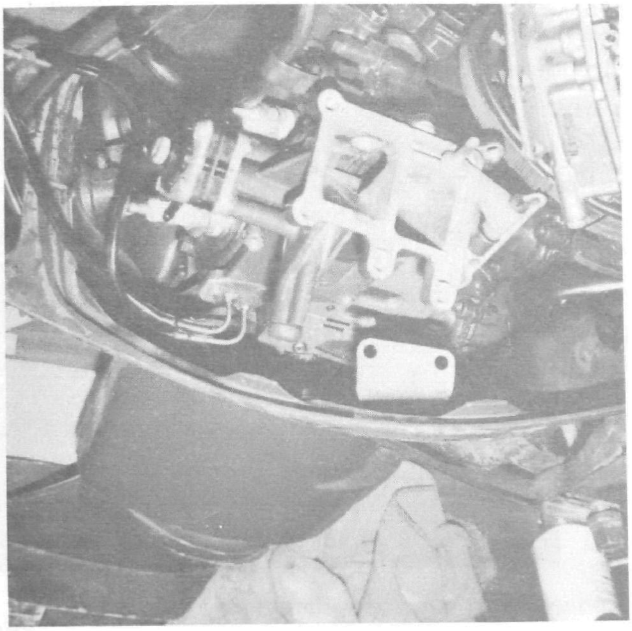

Figure 23. Modified inlet manifold moved back on engine 24 to show check valve and blocked passages

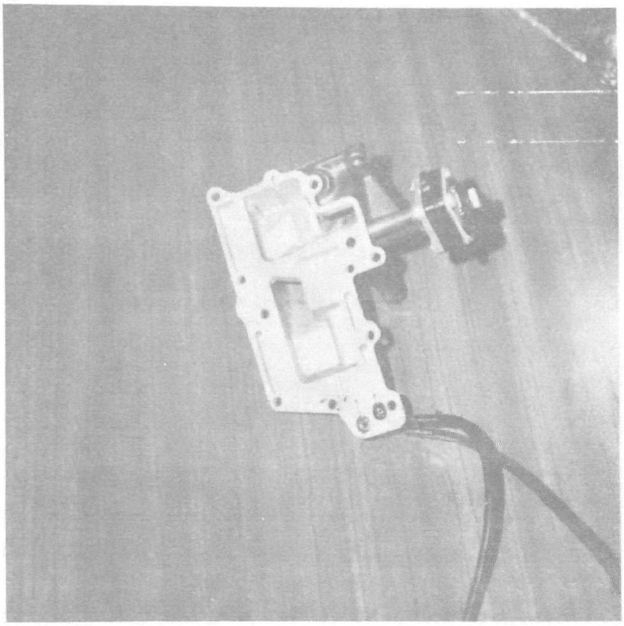

Figure 24. Modified inlet manifold used for tests on engines 24 and 27

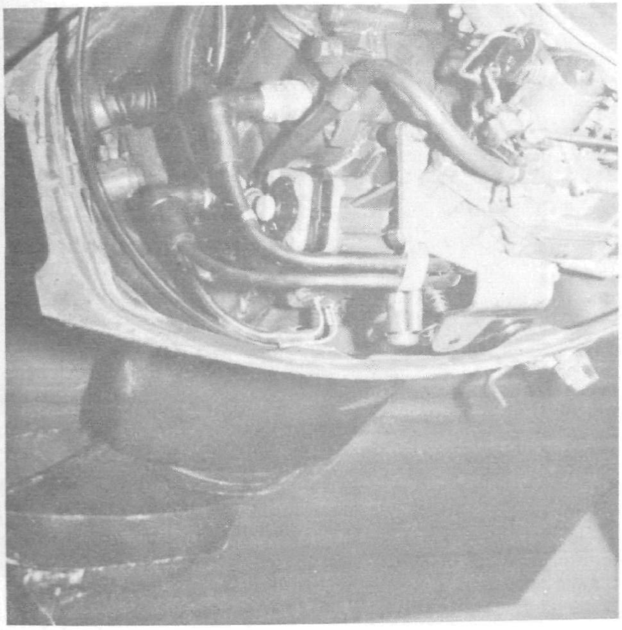

Figure 25. Modified inlet manifold installed on engine 24

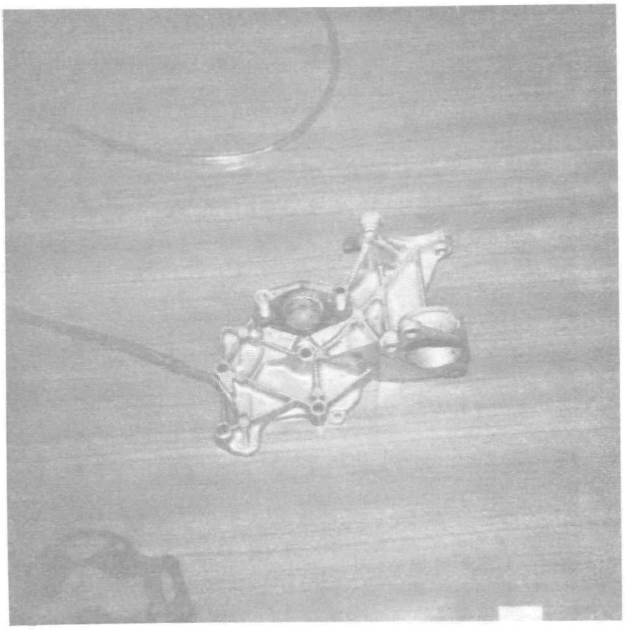

Figure 26. Modified inlet manifold used for tests on engine 26, outside view

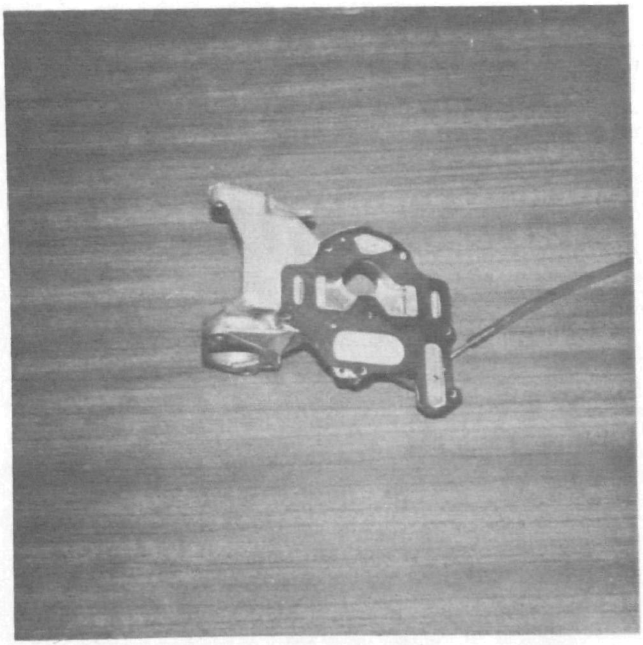

Figure 27. Modified inlet manifold used for tests on engine 26, inside view

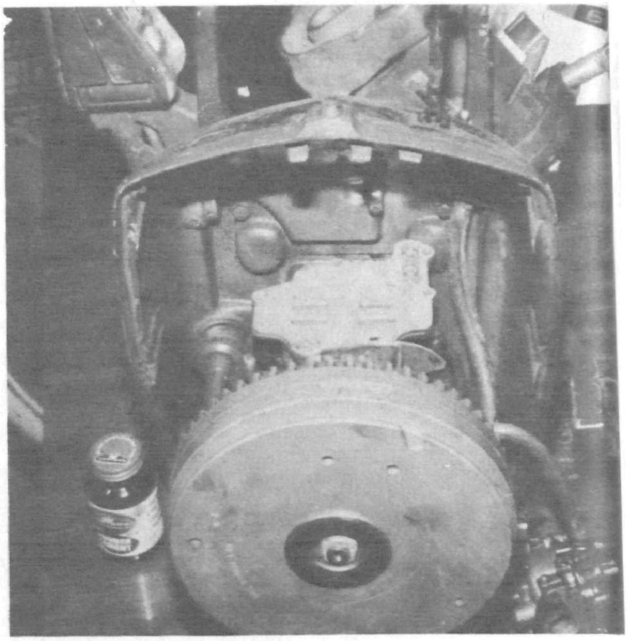

Figure 28. Front face of inlet reed plate, engine 26

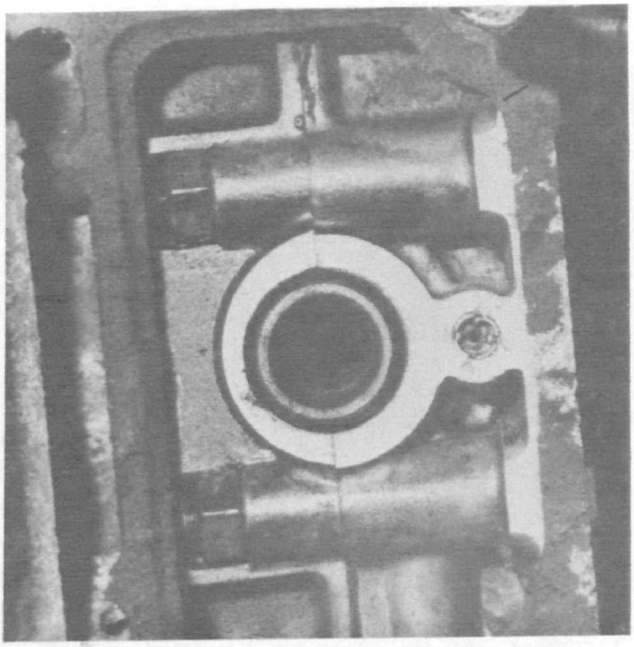

Figure 29. Bottom surface of power-head, engine 29, showing crankshaft and check valve

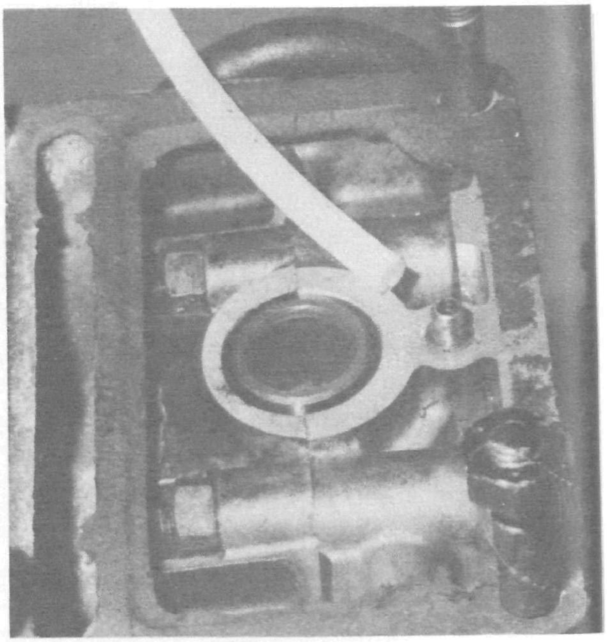

Figure 30. Connector added to check valve on engine 29 for acquisition of sample

the powerhead, with the internally-splined crankshaft at center and the drain check valve right of center (forward of the crankshaft, as assembled). In normal operation, drainage simple dropped into a conical recess surrounding the upper end of the driveshaft and was free to mix with exhaust and cooling water below that point. The modification made is shown in Figure 30 and consisted of sealing (with epoxy) a small brass connector into the recess where the check valve was mounted. The small tube was then attached to the connector and routed out of the motor leg through a hole drilled for the purpose. No gas return line was employed on this engine. It should be noted that the modification described here, or some similar effort, would have been necessary for measurement of drainage from the lower pair of cylinders on all the other Mercury engines tested. Engine 29 was purchased by the contractor so the extensive work could be done, because it was not considered reasonable to ask private owners for permission to do such work on their engines.

In addition to the drainage measurements on the entire group of test engines, the contract included a cursory assessment of a commercially-available drainage interception and recirculation device. This assessment included brief studies of effectiveness and ease of installation, and some tests to determine influence on engine performance. The device is shown disassembled in Figure 31 and consists of the lower chamber (upper left in photo), dividing plate with float valves (lower left), and upper chamber (shown inverted at bottom right of photo). In operation, drainage entered the upper chamber through the off-center fitting, gases were vented to the atmosphere through the center fitting, and liquids accumulated over the dividing plate until one (or both) of the float valves opened. The lower chamber, which is essentially an expansion of the stock fuel line, acts as a mixing zone for the drainage and incoming fresh fuel. A typical permanent installation of this device is shown in Figure 32 with a 9.5 hp motor, and the temporary installation used for a 40 hp motor is shown in Figure 33.

In terms of total effort expended, the crankcase drainage measurements alone represent some 175 hours of engine operation, and evaluations of the drainage interception/recirculation device required about another 30 hours of test time. These figures do not include performance checks, warm-up runs, and other operations which are estimated to total perhaps 100 engine hours. Due to the small size of the pond used for the small motor tests, boats were constrained to operate in a continuous large circle. On Medina Lake, however, a standard test course was established to prevent variations in engine performance due to wind direction. This standardization was not necessary on calm days, but it was used uniformly as a precautionary measure.

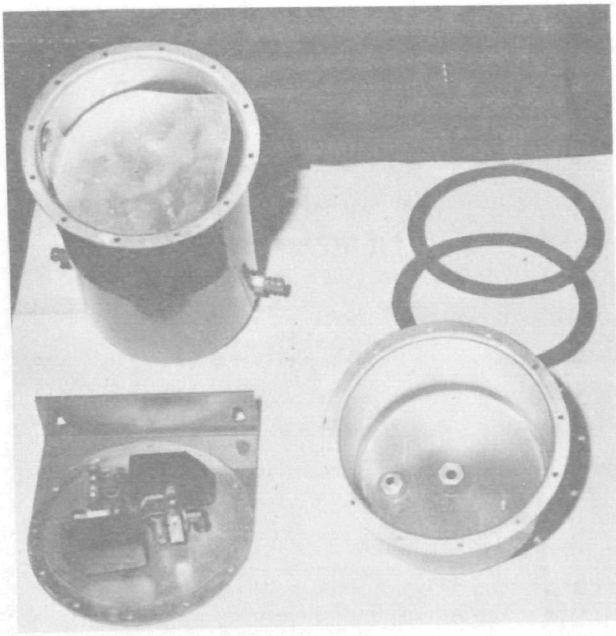

Figure 31. Crankcase drainage interception/recirculation device disassembled

Figure 32. Crankcase drainage interception/recirculation device as installed on a small boat

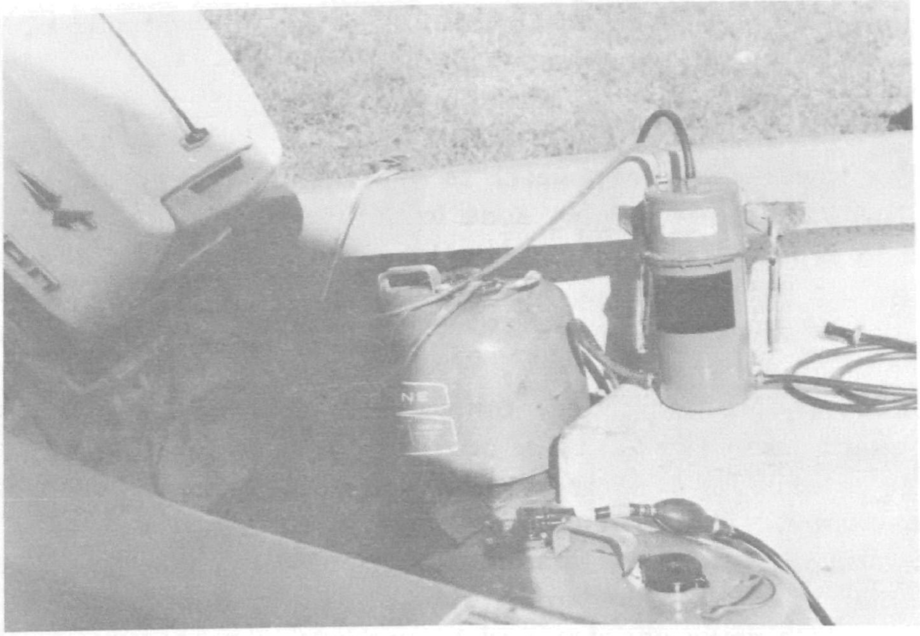

Figure 33. Crankcase drainage interception/recirculation device installed (temporarily) on a larger boat

As additional documentation of the tests, photographs of most of the engines were taken. These photos are included as Appendix B of this report.

SECTION V

CRANKCASE DRAINAGE RESULTS

The test data acquired during field work are given in Appendix A of this report, along with some statistics calculated from the test data. Supplementary details about the motors and boats tested (such as serial numbers, dimensions, and names of owners) are a matter of record but are not considered necessary for this report. Although some indication of motor condition is provided by notes in Appendix A, a more definite statement may be helpful. A summary of the conditions of the motors, judged by how well they operated, is given in Table 7. Note that these judgements were not made by comparison to a specific set of criteria, so they should be regarded as somewhat subjective.

Table 7. SUMMARY OF OPERATING CONDITION OF TEST ENGINES

Condition	Engine numbers
Good	1, 3, 5, 7, 8, 9, 10, 11, 13, 14, 15/15A, 17, 18, 19, 20, 23, 24, 27, 28, 30, 33, 34, 35
Fair	2, 4, 6, 12, 21, 22, 29, 31, 32
Poor	25, 26

In an effort to evaluate the effects of engine tuning on crankcase drainage, it was planned to run the test motors both before and after tuning. In fact, 26 of the 35 motors were tested before and after tuning, with the remainder requiring tuning or repair before they would operate properly. As a general rule, tuning consisted of a spark plug change, a check of timing and condition of points, and test operation to determine optimum carburetor adjustment (if different than the adjustment in "as received" condition). Looking at the tuning changes individually, it becomes evident that the only one which should be expected to change the drainage rate is carburetor (F/A ratio) adjustment. The other tuning operations could be significant if they resulted in a different throttle position for the same crankshaft speed and if this different position caused a change in fuel/air ratio.

Although no data are available on crankcase drainage as a function of ambient conditions, it has been suggested that cooler air temperatures should produce more drainage. The subject study did not address itself to this specific point, and thus no data were acquired on any one engine over a range of ambient conditions. Ambient temperatures during the tests ranged from 60°F to 90°F (16°C to 32°C). Any effect air temperature may have had on the results of this study is probably masked by engine-to-engine variations, so the matter remains undocumented.

The experimental data show that tuning caused little change in drainage, except that due to major carburetor adjustments. For the 25 motors tested both "as received" and "after tuning" (not including 15/15A, which was extensively rebuilt), the drainage during cycles from 17 motors decreased and that from 8 motors increased after tuning. Drainage from 15 motors changed by 10 percent or more (of the initial value) during cycles, with 9 decreases and 6 increases. Drainage during steady-state conditions exhibited changes due to tuning which were very similar to the changes in cycle drainage discussed above. As an average for all 25 motors tested before and after tuning, drainage decreased by about 4 percent of the "as received" value when the motors were tuned. Using these statistics as basis, it appears that engine tuning has at best only a weak influence on drainage. Consequently, the remaining data analysis will neglect tuning as a variable and consider all similar runs (all idles, all cycles, etc.) together for each engine.

Summaries of the drainage data are provided in Tables 8 (in g/hr) and 9 (in weight percent of fuel consumed). Note that in these tables the motors are listed first by groups of similar engines and then numerically. Engines which may have been defective (drainage samples contained water or engine ran poorly) are listed together at the ends of these tables. Note also that all engines in a particular group are not necessarily identical but have at least a basic design in common. The older OMC engines which form group 6 utilized a pressure tank in lieu of a fuel pump, and the pressure tank feature may have had some influence on the amounts of drainage emitted due to diversion of part of the gas and vapor components to the fuel tank. Group 4 is perhaps not obviously homogeneous, but it becomes more so by noting that the Sea King engines tested in group 4 (manufactured by West Bend) bore an unmistakeable resemblance to Chrysler engines of similar size. Whatever the reason for this commonality of design is, it is strong enough to consider the engines as a group.

Although there is generally a great deal of variability in drainage within engine groups, several particular situations warrant further comment. In group 1, it appeared reasonable to include drainage from Engines 24 and 27 with the rest of the OMC 9.5's because their average drainage

Table 8 . CRANKCASE DRAINAGE FROM TEST ENGINES IN g/hr

Motor group	Group description	Motor number	Drainage in g/hr and fuel usage in kg/hr at condition											
			Idle		Low speed		Low mid.		High mid.		High speed		Cycle	
			Drain	Fuel	Drain	Fuel	Drain	Fuel	Drain	Fuel	Drain	Fuel	Drain	Fuel
1	OMC 9.5 hp twins	1	194.	1.70	254.	2.08	178.	3.45	22.2	4.56	60.3	5.03	88.2	3.47
		24[a]	148.	0.93	154.	1.36	99.2	2.66	39.6	3.81	36.2	4.08	89.7	2.72
		27[a]	626.	1.91	570.	2.38	144.	2.99	45.0	4.17	------	-----	213.	3.06
		28	520.	1.41	587.	2.00	186.	2.81	52.6	4.31	78.6	4.54	241.	3.02
		34	398.	1.23	454.	1.71	285.	3.11	56.0	4.32	61.4	4.48	230.	3.18
		35	166.	1.17	257.	1.62	192.	3.02	40.8	4.33	46.6	4.44	143.	3.13
		Average	342.	1.39	379.	1.86	181.	3.01	42.7	4.25	56.6	4.51	167.	3.10
2	OMC V-4 engines	10	1140.	5.41	784.	6.46	76.8	11.4	140.	15.6	303.	21.9	349.	12.5
		15	2450.	5.77	2210.	5.39	1350.	10.0	1220.	13.3	1510.	19.3	1520.	10.8
		15A	1410.	4.01	1390.	5.29	122.	8.62	150.	10.8	900.	17.6	576.	9.73
		18	1430.	5.69	1410.	7.11	864.	10.3	831.	19.0	1360.	22.6	1070.	13.4
		22	1200.	3.71	1320.	4.97	1070.	12.1	882.	14.6	480.	19.7	1030.	10.5
		Average	1520.	4.92	1420.	5.84	696.	10.5	645.	14.7	910.	20.2	908.	11.4
3	30 to 40 hp OMC twins	3	440.	1.79	294.	2.91	95.2	5.15	55.4	9.22	68.6	10.2	116.	6.38
		8	331.	2.34	143.	3.18	35.2	5.26	32.9	11.1	------	-----	80.9	7.23
		13	627.	2.97	357.	3.95	108.	5.75	58.8	8.07	84.8	9.93	201.	6.24
		33	87.6	1.85	50.1	2.44	19.6	3.75	17.4	7.24	34.8	10.4	36.8	5.19
		Average	371.	2.24	211.	3.12	64.5	4.98	41.1	8.91	62.7	10.2	109.	6.26
4	35 to 55 hp Chrysler and Sea King twins	6	275.	1.45	13.8	2.81	4.4	7.16	7.0	12.9	12.0	18.1	56.0	7.61
		11	219.	1.79	11.4	4.56	1.3	6.99	-----[b]	10.8	0.8	16.3	12.8	7.92
		19	7.1	2.77	3.0	3.44	0.8	7.29	-----[b]	10.3	5.9	13.9	3.3	7.87
		20	306.	2.00	31.0	2.79	3.2	6.02	1.4	8.66	11.4	13.3	38.7	6.87
		32	17.8	2.25	8.3	3.53	5.1	5.95	4.6	8.47	3.0	10.9	6.4	6.35
		Average	165.	2.05	13.5	3.43	3.0	6.68	2.6	10.2	6.6	14.5	23.4	7.32

Table 8. (continued). CRANKCASE DRAINAGE FROM TEST ENGINES IN g/hr

Motor group	Group description	Motor number	Drainage in g/hr and fuel usage in kg/hr at condition											
			Idle		Low speed		Low mid.		High mid.		High Speed		Cycle	
			Drain	Fuel	Drain	Fuel	Drain	Fuel	Drain	Fuel	Drain	Fuel	Drain	Fuel
5	4- and 6-cyl. Mercury engines	4	41.1	2.31	66.6	6.12	96.8	11.2	19.8	14.8	------	-----	61.2	11.7
		7	18.8	2.34	14.8	2.95	22.4	6.65	10.4	8.16	6.8	10.9	12.2	5.92
		14	72.4	1.75	174.	5.33	98.1	10.3	46.2	15.4	30.9	25.4	89.6	11.7
		16	135.	3.52	38.4	5.19	28.5	9.95	11.2	11.2	13.6	20.1	30.6	11.6
		17	87.1	3.36	164.	6.17	40.0	9.04	-----[b]	12.6	-----[b]	18.1	55.3	10.0
		Average[c]	59.1	2.66	76.3	5.16	47.6	9.43	14.6	12.4	10.3	18.6	41.5	10.2
6	OMC twins using pressure tank (older)	5	61.6	1.46	102.	1.67	31.4	3.95	37.0	5.03	50.2	6.06	54.6	3.71
		12	302.	2.9	228.	3.1	184.	4.4	50.4	6.9	41.1	8.6	111.	4.0
		21	31.4	3.70	8.3	7.44	10.5	8.98	13.4	10.3	------	-----	9.6	8.35
7	OMC 18 hp twins	2	157.	1.26	186.	2.31	76.9	4.35	23.0	5.68	17.7	6.36	74.4	4.71
		31[a]	128.	1.79	56.2	2.21	39.7	3.68	35.8	5.43	33.8	6.83	45.8	4.17
		Average	142.	1.52	121.	2.26	58.3	4.02	29.4	5.56	25.8	6.60	60.1	4.44
Miscellaneous														
(Chrysler 5 hp)		23	74.0	0.78	2.2	0.75	66.4	1.50	266.	2.38	230.	2.45	124.	1.60
(Mercury 9.8 hp)		30[a]	63.5	0.49	65.2	0.73	68.4	1.60	10.8	2.24	11.0	3.22	26.9	1.73
Defective[d]														
(Johnson 40 hp)		9	334.	3.18	425.	4.20	218.	7.77	72.8	10.6	28.6	13.2	186.	8.30
(Johnson 9.5 hp)		25	12.8	1.60	8.1	1.94	9.0	3.31	44.1	4.49	------	-----	25.5	3.06
(Johnson 6 hp)		26	17.8	0.64	37.1	0.88	9.5	1.45	3.6	2.27	------	-----	10.7	1.54
(Mercury 6 hp)		29	44.2	0.57	35.5	0.82	130.	1.00	125.	1.22	17.0	1.81	69.6	1.11

[a] Originally drainless engine converted to drained configuration for tests.

[b] Too small to measure.

[c] Based on assumed 4-cylinder engine.

[d] Water in samples or very poor operation.

Table 9. CRANKCASE DRAINAGE FROM TEST ENGINES IN WEIGHT PERCENT OF FUEL CONSUMED

Motor group	Group description	Motor number	Drainage in weight percent of fuel consumed					
			Idle	Low speed	Low mid.	High mid.	High speed	Cycle
1	OMC 9.5 hp twins	1	11.5	12.5	5.22	0.510	1.21	2.54
		24[a]	16.4	11.4	3.81	1.06	0.894	3.30
		27[a]	33.0	24.1	4.81	1.08	-----	6.94
		28	37.1	29.5	6.60	1.24	1.73	8.04
		34	32.4	26.7	9.17	1.38	1.37	7.24
		35	14.1	15.9	6.29	0.943	1.06	4.55
		Average	24.1	20.0	5.98	1.04	1.25	5.44
2	OMC V-4 engines	10	21.0	12.0	0.692	0.897	1.38	2.80
		15	42.4	41.0	13.4	9.23	7.80	14.2
		15A	35.2	26.4	1.39	1.40	5.11	5.92
		18	25.3	19.7	8.08	4.33	6.01	7.93
		22	32.1	26.6	8.86	6.09	3.88	9.80
		Average	31.2	26.9	6.48	4.39	4.84	8.13
3	30 to 40 hp OMC twins	3	24.8	10.1	1.84	0.601	0.671	1.82
		8	14.2	4.52	0.665	0.335	-----	1.12
		13	21.2	9.05	1.89	0.733	0.854	3.22
		33	4.64	2.08	0.516	0.240	0.336	0.709
		Average	16.2	6.44	1.23	0.477	0.620	1.72
4	35 to 55 hp Chrysler and Sea King twins	6	19.7	0.445	0.062	0.054	0.066	0.734
		11	12.3	0.375	0.02	-----[b]	0.01	0.161
		19	0.257	0.044	0.010	-----[b]	0.045	0.042
		20	15.3	1.11	0.054	0.016	0.087	0.564
		32	0.785	0.244	0.084	0.055	0.028	0.101
		Average	9.67	0.444	0.046	0.025	0.047	0.320

Table 9. (continued). CRANKCASE DRAINAGE FROM TEST ENGINES IN WEIGHT PERCENT OF FUEL CONSUMED

Motor group	Group description	Motor number	Drainage in weight percent of fuel consumed					
			Idle	Low speed	Low mid.	High mid.	High speed	Cycle
5	4- and 6-cyl. Mercury engines	4	1.76	1.09	0.864	0.134	-----	0.521
		7	0.825	0.508	0.336	0.129	0.062	0.205
		14	1.76	2.18	0.636	0.201	0.081	0.510
		16	3.85	0.737	0.285	0.165	0.068	0.263
		17	2.59	2.91	0.439	-----[b]	----[b]	0.560
		Average	2.16	1.48	0.512	0.126	0.053	0.412
6	OMC twins using pressure tank (older)	5	4.21	6.08	0.784	0.734	0.840	1.48
		12	10.6	7.27	4.16	0.722	0.480	2.76
		21	0.983	0.108	0.106	0.138	-----	0.115
		Average	5.26	4.49	1.68	0.531	0.660	1.45
7	OMC 18 hp twins	2	11.6	7.79	1.76	0.400	0.276	1.56
		31[a]	7.12	2.57	1.08	0.661	0.515	1.13
		Average	9.36	5.18	1.42	0.530	0.396	1.34
Miscellaneous								
(Chrysler 5 hp)		23	9.62	0.308	4.44	11.2	8.47	7.84
(Mercury 9.8 hp)		30[a]	12.9	8.87	4.29	0.48	0.35	1.56
Defective[c]								
(Johnson 40 hp)		9	10.6	10.1	2.81	0.693	0.220	2.23
(Johnson 9.5 hp)		25	0.781	0.414	0.273	0.988	-----	0.833
(Johnson 6 hp)		26	2.87	4.19	0.678	0.771	-----	0.671
(Mercury 6 hp)		29	7.82	4.29	12.9	10.4	0.933	6.28

[a] Originally drainless engine converted to drained configuration for tests.
[b] Too small to measure.
[c] Water in samples or very poor operation.

was much like that of the rest of the group. This inclusion was questioned on technical grounds earlier due to the differences in carburetion on the drain-controlled models, but the objection does not appear to be justified by the data in this case. To be on the safe side, however, data from converted drainless engines will not be used in estimating national drainage totals later in the report. In two other situations (Engines 15 and 9), drainage appeared to be far from the group norm (higher for Engine 15 and lower for 9), but no defect in the engines could be found which might have affected drainage. These two engines were accepted as representing some of the variability to be experienced in drawing a sample from private ownership. In general, drain percentage from groups 1 and 2 was comparatively high; that from groups 4 and 5 was comparatively low; and drain percentage from groups 3, 6, and 7 was somewhere in the middle.

In group 4, motors 19 and 32 exhibit much lower drainage at idle than the other three in the group. Since it is known that Chrysler (and Chrysler-like) motors utilized a partial drainage control system in years prior to total control, it must be assumed that the characteristics of the partial control systems changed enough from one model or year to another to produce different drainage patterns. Engine 31 was included with Engine 2 to form group 7 under essentially the same justification as used to include Engines 24 and 27 in group 1.

There is no real basis for averaging drainage or fuel mass rates across group 6, but the average given in Table 9 is of drain percentages for which a certain common ground can be assumed (engine design features). The same reasoning shows that there is no justification for averages of drainage or fuel consumption over the "miscellaneous" and "defective" groups. Going a little further into the interpretation of "defective", the primary criterion for placing a motor in this group was presence of water in the drainage samples. Water in the drainage indicates leakage of the bottom crankshaft seal, and it can usually be assumed that drainage can escape where water can leak in. If drainage escapes through the seal and is not measured, the reported results would understate drainage from that engine. Motor No. 26 was placed in the defective category because it simply did not run very well and would probably have been repaired before being used again in the field.

Figures 34 and 35 are presented to show data from Tables 8 and 9 graphically. Figure 34 shows average drainage rates from groups 1-5 and group 7 as recorded in Table 8, including drainage both as a function of crankshaft speed and during cycles. In terms of total drainage rates, group 2 (OMC V-4's) stands apart at the high end of the scale. Groups 1 and 3 (OMC 9.5 hp twins and OMC 30-40 hp twins) occupy the middle of the scale,

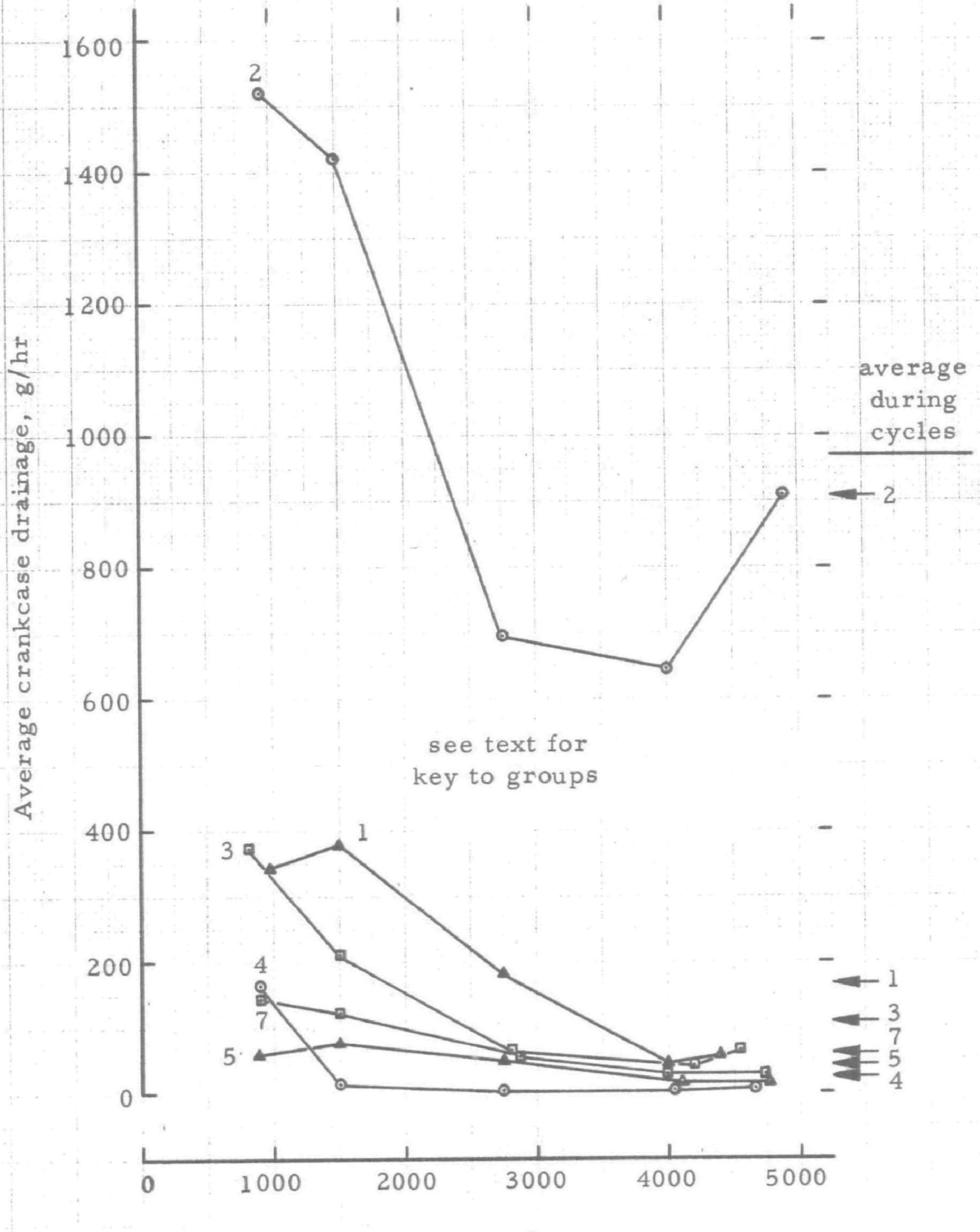

Figure 34. Average crankcase drainage (mass rates) for six engine groups, during cycles and as functions of engine speed

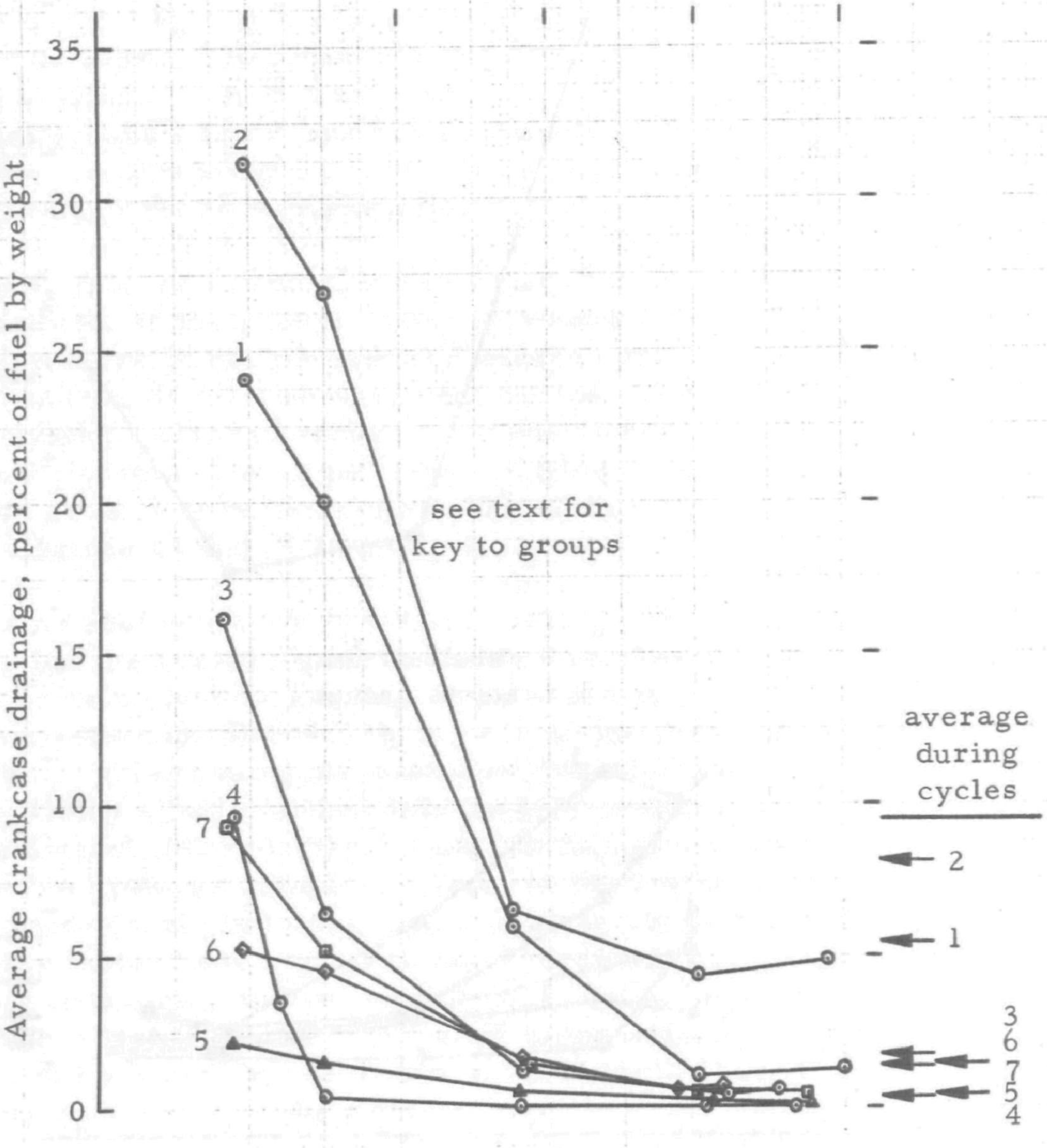

Figure 35. Average crankcase drainage (weight percent of fuel) for seven engine groups, during cycles and as functions of engine speed

and the other groups (7, 4, 5) are fairly close at the low end. Drainage during cycles is indicated by the arrows at the right side of the graph.

In Figure 35, group 2 shows the highest percent drainage rates, followed closely group 1. The other percentage rates are scattered down the scale, and the cycle averages are given at the right as in Figure 35. Both Figures 34 and 35 show a strong variation in drainage with engine speed and engine type. The percentages are more strongly dependent on engine speed than the mass rates are, of course, since fuel consumption increases sharply with engine speed (and power output). In Figure 35, an extra data point (at 1200 rpm) is shown for group 4 (35 to 55 hp Chryslet twins). Several engines were run at this condition after it had been observed that drainage underwent a very sharp drop between idle and 1500 rpm for this group, in an attempt to define the curve more precisely in the transition region.

Drainage from cyclic operation of the "miscellaneous" and "defective" engine groups fell into the same range as that from groups 1 to 7. The range for these extra groups was from 0.67 percent to 7.84 percent of fuel by weight recovered as drainage, as compared to a range from 0.10 percent to 14.2 percent of fuel by weight for individual engines in groups 1 to 7. As mentioned before, however, drainage from some (or all) of the "defective" engines may be understated by the data; because some drainage could have escaped into the water without being collected.

Drainage emitted from three of the "defective" engines (Nos. 9, 25, and 29) did contain water, as documented by Figures 36 through 38. The water appeared to be physically mixed with drainage to some extent, and further "settling" of the two layers occurred when the samples stood for several days. Several methods were employed to separate the hydrocarbon and water phases, including decanting and absorbing the aqueous phase with a dessicant. The most successful technique was removal of the aqueous phase through a long hypodermic needle, permitting the remaining fuel-based material to be measured volumetrically and to be weighed in the normal manner. The white appearance of the water layer in Figures 36 through 38 was apparently due to partial mixing of water and hydrocarbon materials, causing a certain amount of emulsification. After an extended period without agitation, some clarity returned to the water phase, with more change being evident for those samples which contained more water than drainage.

After the initial series of tests had been conducted (through Engine No. 29), attempts were made to re-acquire Engines 9 and 25 for further tests (Engine 29 stayed in the contractor's possession). These attempts failed to locate the engines, but further tests were run on Engine No. 29 in a

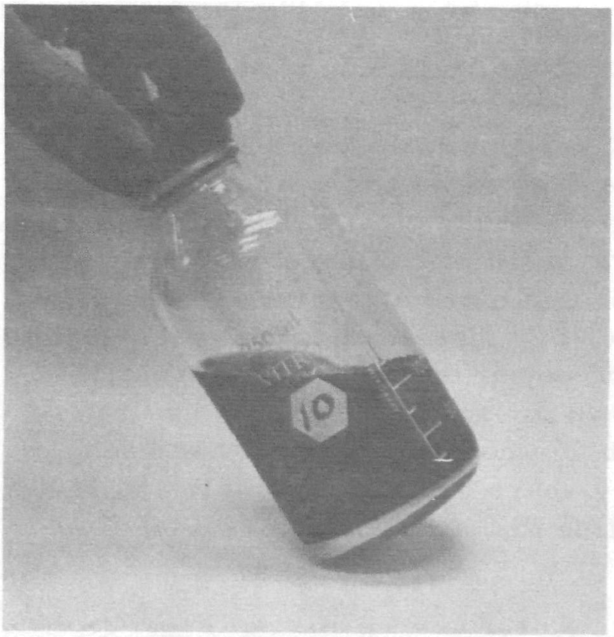

Figure 36. Typical sample from engine 9 showing water layer under drainage

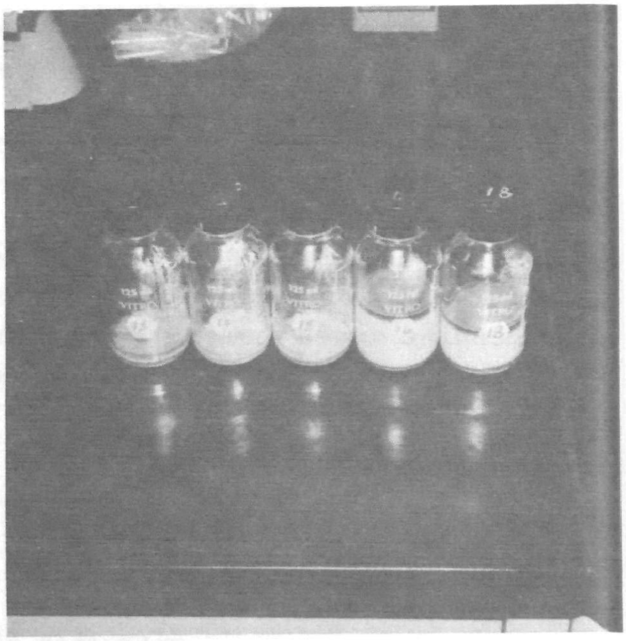

Figure 37. Drainage samples from motor no. 25 showing water layers under fuel-based material

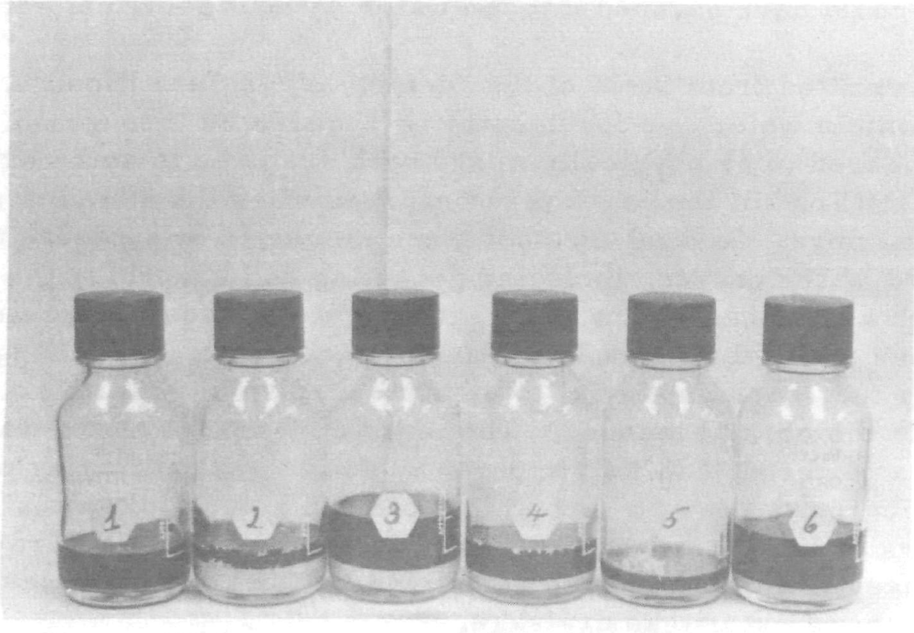

Figure 38. Drainage samples from engine 29 showing water layers under fuel-based material

stationary tank. The tests showed that water present in the drainage was leaking into the crankcase from the water in which the engine was operated (presumably through a seal or crack). This conclusion was reached by tracing a compound added to the tank water supply into the drainage, indicating that at least part of the water consisted of leakage rather than condensation of atmospheric moisture. No conclusions were possible, of course, for Engines 9 and 25.

It is considered to be of interest that of the 35 engines tested, three did have water in the drainage, indicating leakage through crankshaft seals. This result indicates that the entire population of outboards may contain a considerable number of engines having crankshaft seals which leak.

SECTION VI

RESULTS OF TESTS USING A DRAINAGE INTERCEPTION/RECIRCULATION DEVICE

As part of the subject research program, it was requested that the contractor run limited tests intended to gather data on the operability and effectiveness of a commercially available drainage interception/recirculation device. Photographs of the device have been presented in Section IV (Figures 31 to 33), along with a discussion of its operation. The device was tested on four motors in all, specifically those numbered 9, 18, 28, and 29 in the drainage survey (OMC 40 hp twin, OMC 85 hp V-4, OMC 9.5 hp twin, and Mercury 6 hp twin, respectively).

If the recirculating device is connected to the engine according to instructions, it intercepts all the drainage materials (except possibly from some Mercury motors) and returns the liquids to the fuel supply. Gases and vapors are simply vented to the atmosphere. Referring back to Figure 7 (Section IV), the unit intercepts drainage in the same way as the bottle shown in Figure 7b, but gases and vapors are released to the atmosphere instead of being returned to the motor leg. The exception noted above for some Mercury motors is based on the construction of the Mercury drain systems, shown schematically in Figure 14. Hardware supplied with the device for use with Mercury 4- and 6-cylinder motors consists of a "tee" and some tubing. The "tee" is inserted in the drainage line at the place called "sampling point" in Figure 14, which permits drainage from the upper pair(s) of cylinders to be diverted to the recirculating device *if* pressure in the drainage line is sufficiently higher than atmospheric. Since both the run and the branch of the tee are open, however, drainage materials could still escape via their normal route if that were the path of least resistance. No provision or instruction supplied with the device indicates that any attempt is made to intercept drainage from the lowest pair of cylinders, since doing so would require removal of the powerhead from the motor leg and some modifications. This problem also means that the device will not work on 2-cylinder Mercury motors unless they are modified like Engine 29 was modified for this project.

Noting that the gas and vapor components of the drainage are vented into a region of atmospheric pressure from the upper chamber of the recirculating device, it is possible that the amount of liquid collected from an engine equipped with a device may exceed the drainage from one which is unaltered. Referring back to Figure 1, crankcase drainage valves (either check valves or leaf valves) are opened by pressure differential from the crankcase to the system downstream of the valve. In unaltered condition, the system downstream of the drainage valve is usually a passage leading to the motor leg. Due to the flows of exhaust and water through the motor leg, its internal pressure must be somewhat higher than atmospheric. This line of reasoning shows that the pressure head against which crankcase pressure pushes to open the drainage valve is lower when the intercepting device is installed, making it plausible that engines with intercepting systems installed pass somewhat more drainage through the valve than stock engines do.

The initial testing of the four motors mentioned earlier with the device installed consisted of short-term cyclic operation. Each engine was run on several 20-minute and/or 40-minute cycles, with time in each operating condition apportioned according to Table 4b. Total operating time in these initial tests was 4 hours 20 minutes each for Motors 9 and 18, 4 hours for Motor 28, and 1 hour for Motor 29. The presence of the device had no noticeable effect on engine operation during these short tests.

Longer-term tests were conducted with the interception/recirculation device connected to Motors 18 and 29. The tests on Unit 29 included cycles, timed accelerations, and extended idle and low speed operation. This engine was of particular interest because it had been observed to emit some water along with fuel-based drainage material, as discussed in Section V and as shown in Figure 38. It is assumed that water in the drainage resulted from a defective lower crankshaft seal. The schedule of tests used for Engine 29 is shown in Table 10, along with data on acceleration times and points at which fuel samples were taken. The operation of the engine did not seem to be affected by the presence of the recirculating device during these tests, but Figures 39 through 43 provide some insight into effects which would have resulted from even longer operation.

Figure 39 shows the test tank and equipment used for the steady-speed evaluation procedure. Figure 40 shows the interception/recirculation unit after about one hour of operation at 2750 rpm, and the drainage level in the top chamber was about 0.7 inch (the view ports were installed for better visualization of device operation). Figure 41 shows the unit at about 90 minutes of operation, just before the drainage material began to enter the lower chamber through the float-controlled valves. Figure 42 was taken about five hours into the test and Figure 43 at the end of the stationary test (5 hours 43 minutes). Both these figures show the water layer building up in the top chamber. Engine 29 did not emit a great deal of drainage or water, so it was considered impractical to continue its

Table 10. TEST SCHEDULE FOR ENGINE 29 (WITH AND WITHOUT INTERCEPTION/RECIRCULATION) DEVICE

Run	Device installed	Description of operation	Time at		Acceleration times, seconds	Fuel Sample	Boat or tank test
			Start	End			
1	No	Cycle[a]	0	20m	-------------	10	Boat
		Idle - 5400 rpm accel.	20m	------	4.0	------	
		Idle - 5400 rpm accel.	21m	------	4.0	------	
		Idle	----	23m	-------------	------	
2	No	Cycle[a]	0	20m	-------------	11	Boat
		Idle - 5400 rpm accel.	20m	------	3.5	------	
		Idle - 5400 rpm accel.	21m	------	3.5	------	
		Idle	----	23m	-------------	12	
3	Yes	2750 rpm[b]	0	5h 43m	-------------	------	Tank
4	Yes	Cycle[a]	0	20m	-------------	------	Boat
		Idle - 5400 rpm accel.	20m	------	3.5	------	
		Idle - 5400 rpm accel.	21m	------	3.0	------	
		Idle	----	23m	-------------	13	
5	Yes	Cycle[a]	0	20m	-------------	------	Boat
		Idle - 5400 rpm accel.	20m	------	3.5	------	
		Idle - 5400 rpm accel.	21m	------	3.0	------	
		Idle	----	23m	-------------	14	

[a] See Tables 4b and 5 for cycle description.

[b] Drainage rate at this condition about 13% of fuel by weight (see Table 9)

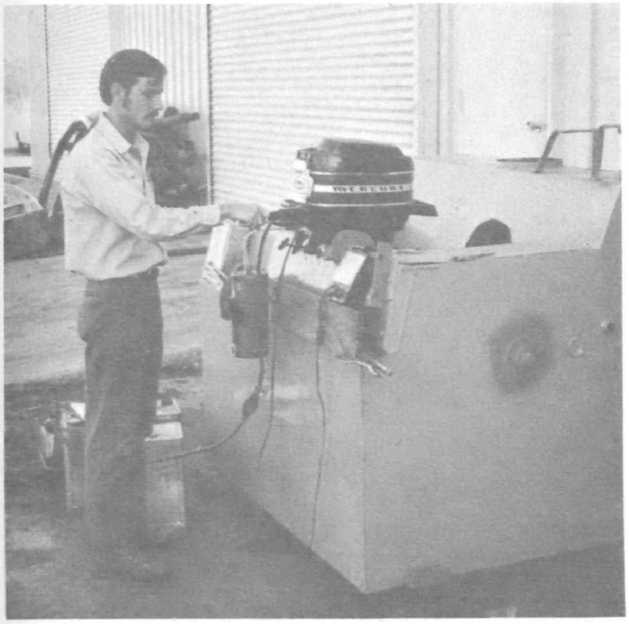

Figure 39. Stationary tank test of Mercury 6 hp motor with interception/recirculation device

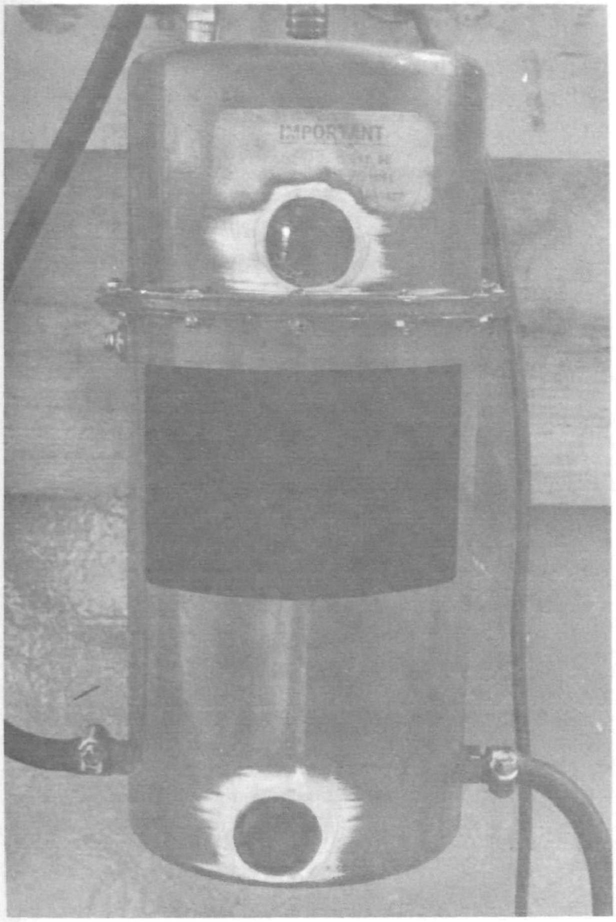

Figure 41. Device after about 1.5 hours of operation

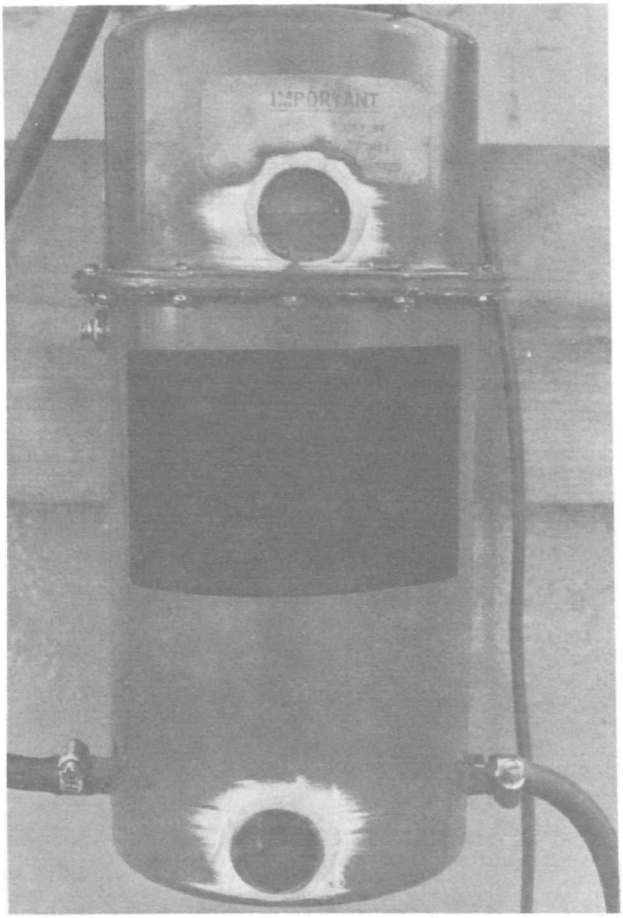

Figure 40. Drainage interception/recirculation device after about one hour of operation

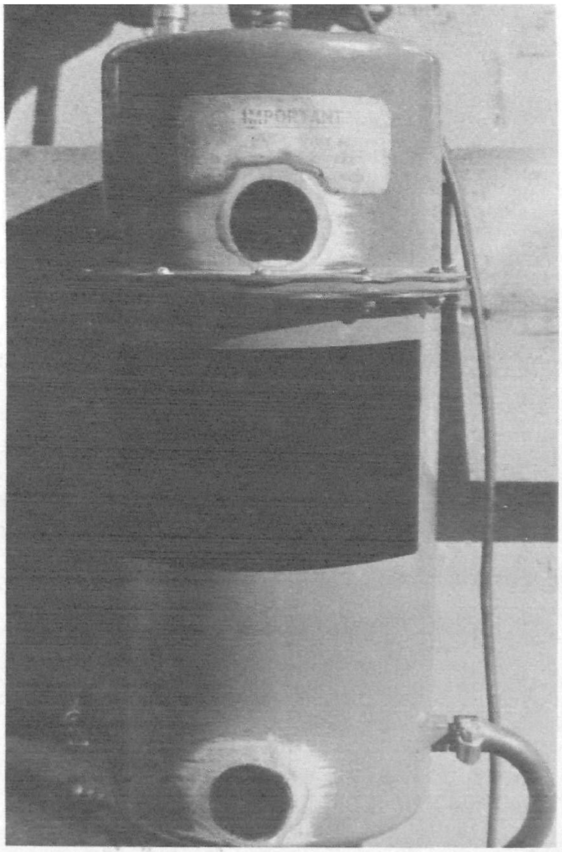

Figure 42. Drainage interception/ recirculation device after about five hours of operation on unit 29

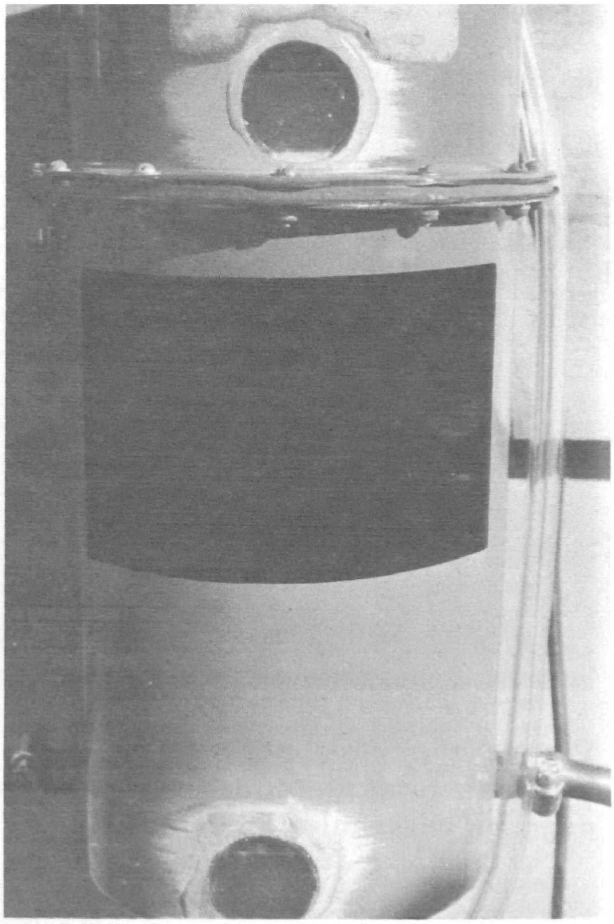

Figure 43. Device after five hours 43 minutes of operation (end of test) on engine 29

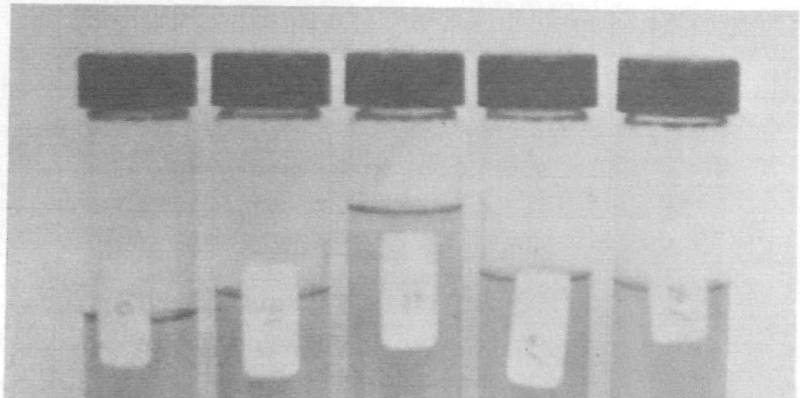

Figure 44. Fuel samples taken from line downstream of recirculation device for engine 29 (sampling times shown in Table 10)

operation to the point at which sufficient water had built up in the lower chamber to stop the engine. Engine stoppage by choking the fuel system with water would have occurred much more rapidly for an engine which emitted more water, such as Engine 25 (see Figure 37). This engine stoppage is not necessarily a disadvantage of the device, because it would alert the motor owner that a problem existed, and he might be able to have his engine repaired before serious damage occured (such as from storage of an engine over the winter with water in the crankcase). It was also observed that the water fractions of some drainage samples had a high viscosity, more or less in proportion to their degree of turbidity. Note in Figure 36, for instance, that the water fraction in the sample did not form a horizontal interface with the fuel-based material when the bottle was tilted. This particular property of the aqueous layer could cause the orifices of the float-controlled valves in the recirculating device to plug when water reached their level (in the top chamber), which would cause the top chamber to overflow through its vent tube and render the device ineffective.

To conclude the discussion on operation of motor No. 29 with the recirculating unit installed, Figure 44 shows the five fuel samples referred to in Table 10. Note that the photo was purposely focused on the grid behind the samples to show the turbidity of samples 13 and 14, both of which were taken after the point at which drainage had begun to mix with fresh fuel. Samples 10 to 12, which are quite transparent, were taken before the device was installed.

Engine 18, an OMC 85 hp unit, was also operated extensively with the interception/recirculation unit installed. The schedule of tests used for Engine 18 is shown in Table 11, along with other data. The initial tests (runs 1 to 4) were essentially the same as cyclic tests run on all the test engines, except for extra length and the acceleration tests added. The acceleration tests were run against a tachometer rather than a speedometer because the latter was not available for these tests. Installation and use of the device did not cause any noticeable change in engine performance during cyclic operation in runs 3 and 4. Control runs without the device installed were not performed; therefore, no conclusions can be drawn regarding whether engine performance was improved or degraded due to use of the device in runs 5 through 7.

The (temporary) installation of the device used with Engine 18 is shown in Figure 45, and the arrangement of valves shown in Figure 46 permitted the engine to be operated with the unit either in or out of the system without interchanging any parts. Figure 47 shows the nine fuel samples taken at the times shown in Table 11. Sample color varied from light yellow-green (fresh fuel) for the first few samples to a dark green-brown

Table 11. TEST SCHEDULE FOR ENGINE 18 (WITH AND WITHOUT RECIRCULATING DEVICE)

Run	Recirculating device installed	Description of operation	Time (minutes: seconds) at		Acceleration times, seconds	Fuel sample
			Start	End		
1	No	Cycle[a]	0	40:00	----------------	1
		Idle - 5000 rpm accel.	40:00	----	7.0	------
		Idle - 5000 rpm accel.	42:00	----	6.0	------
		Idle	----	43:57	----------------	2
2	No	(Same as run 1)	0	42:55	8.0 (1 accel. only)	3
3	Yes	(Same as run 1)	0	42:57	7.0, 5.5	4, 5
4	Yes	(Same as run 1)	0	42:54	8.0, 6.0	6
5 *	Yes	Idle	0	5:00	----------------	------
		1500 rpm	5:00	20:00	----------------	------
		Idle[b]	20:00	25:00	----------------	------
		1500 rpm	25:00	40:00	----------------	------
		Idle	40:00	48:00	----------------	------
		Idle - 5000 rpm accel.	49:00	----	9.0	------
		Idle - 5000 rpm accel.	50:00	----	10.0	------
		Idle[c]	----	50:50	----------------	7
6 *	Yes	(First 40 min. like run 5)[d, e]	0	40:00	----------------	------
		Idle[f]	40:00	43:00	----------------	------
		Idle - 5000 rpm accel.	44:00	----	12.0	------
		Idle - 5000 rpm accel.	45:00	----	8.0	------
		Idle	----	45:35	----------------	8
7 *	Yes	(First 40 min. like run 5)[f]	0	40:00	----------------	------
		Idle[g]	40:00	43:40	----------------	------
		Idle - 5000 rpm accel.	44:00	----	9.0	------
		Idle - 5000 rpm accel.	44:40	----	7.0	------
		Idle	----	45:04	----------------	9

[a] Twice through 20 minute cycle described in Tables 4b and 5.
[b] Engine started missing.
[c] Engine died twice and ran roughly.
[d] Engine died three times and ran very roughly.
[e] Engine died twice and ran very roughly.
[f] Engine died six times and ran very roughly.
[g] Engine died three times.

***Note:** Control runs without device installed were not performed; therefore, no conclusions can be drawn regarding whether engine performance was improved or degraded due to use of the device.

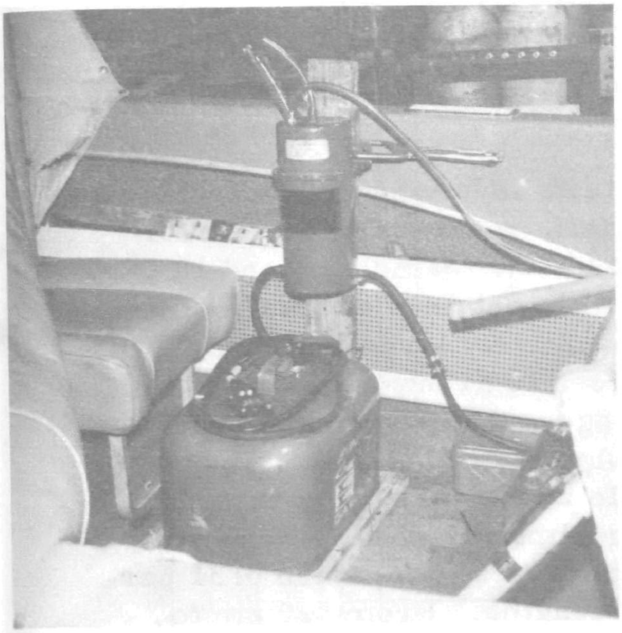

Figure 45. Installation of interception/recirculation device for operation of engine 18

Figure 46. Valve system used to switch between stock and device-equipped configurations for engine 18

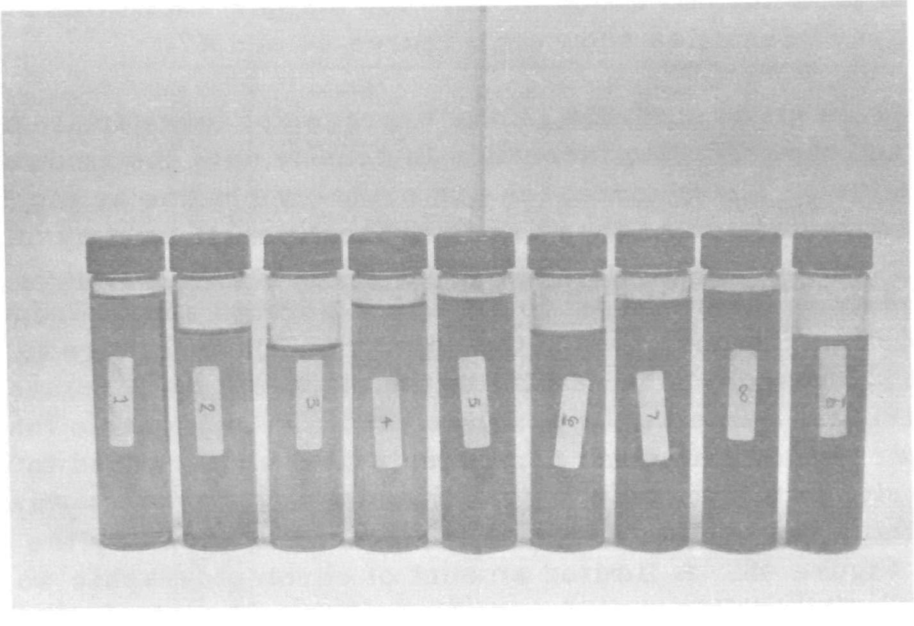

Figure 47. Fuel samples taken from line downstream of recirculating device for engine 18 (sampling times shown in Table 11)

for the last few samples. The base gasoline color was a light yellow-orange, and the OMC oil used was a dark blue-green. This photo is not a quantitative indicator of the difference between fresh fuel and fuel mixed with drainage, but it does help visualize the changes which occured.

Several of the fuel samples taken during tests involving the recirculating device were studied in substantial detail, specifically those numbered 1, 4, 5, 9, 10, and 14 (Tables 10 and 11). Samples 1 and 10 contained no drainage, samples 4, 6, and 14 contained at least some drainage, and sample 9 contained a comparatively large fraction of drainage. Samples 1 to 9 were yellow-green to green-brown in color, while samples 10 and 14 were yellow-orange. As shown in Table 12, sample densities were measured using volumetric flasks at 20C, and percent light transmittance of each sample was measured at three wavelengths (optical path through sample approximately 1 cm). The strongest trend was an increase in transmittance (average increase 0.31 per 100 nm) between 450 nm and 520 nm wavelengths. From 520 nm to 650 nm, the transmittance of samples 1, 4, 6, and 9 stayed nearly the same (average increase of 0.017 per 100 nm). The transmittance of samples 10 and 14 increased markedly between 520 nm and 650 nm (average increase 0.18 per 100 nm), indicating that they pass more light toward the red end of the visible spectrum. These transmittance results confirm expectations based on both the sample colorations and the apparent "gray" densities shown in Figures 44 and 47.

The density figures given in Table 12 are averages of three trials on each sample, and they indicate increases in density with the amount of drainage in the fuel. These increases are probably not due as much to increased oil concentration as they are to evaporation of light gasoline-range hydrocarbons in the engine crankcase. In other words, the "light ends" of the inducted gasoline tend to remain vaporized and be inducted into the combustion chamber, while the "heavy ends" tend more to remain as liquid (drainage). The density of the oil itself (as it comes from the can) is nearly the same as the gasoline used. It is probable that the lower molecular weight "dilution" components of the oils (added to the high-lubricity stocks to decrease overall viscosity and enhance mixing) fall mainly within the gasoline range of hydrocarbons shown by the chromatograms in Figure 48. A limited amount of chromatographic work indicates that the light "dilution" components of the oil elute from the column in 2 to 6 minutes and account for perhaps 20 percent of the oil by weight. No "hump" appears in the chromatograms shown in Figure 48 to indicate the oil's presence because it is present in rather low concentrations (2 percent to perhaps 5 percent).

Table 12. MASS DENSITY AND LIGHT TRANSMITTANCE OF FUEL SAMPLES FROM TESTS INVOLVING A DRAINAGE RECIRCULATION DEVICE

Fuel sample	Engine number	Comparative drainage amount present	Density, g/ml at 20C	Light transmittance at wavelength (nm)[a]		
				450 (blue)	520 (green)	650 (red)
1	18	None	0.720	0.32	0.57	0.59
4	18	Small	0.725	0.40	0.62	0.60
6	18	Small	0.750	0.22	0.42	0.44
9	18	Large	0.774	0.05	0.16	0.23
10	29	None	0.729	0.34	0.60	0.85
14	29	Small	0.736	0.13	0.40	0.71

[a] nm is abbreviation for nanometer (1nm = 10^{-9}m)

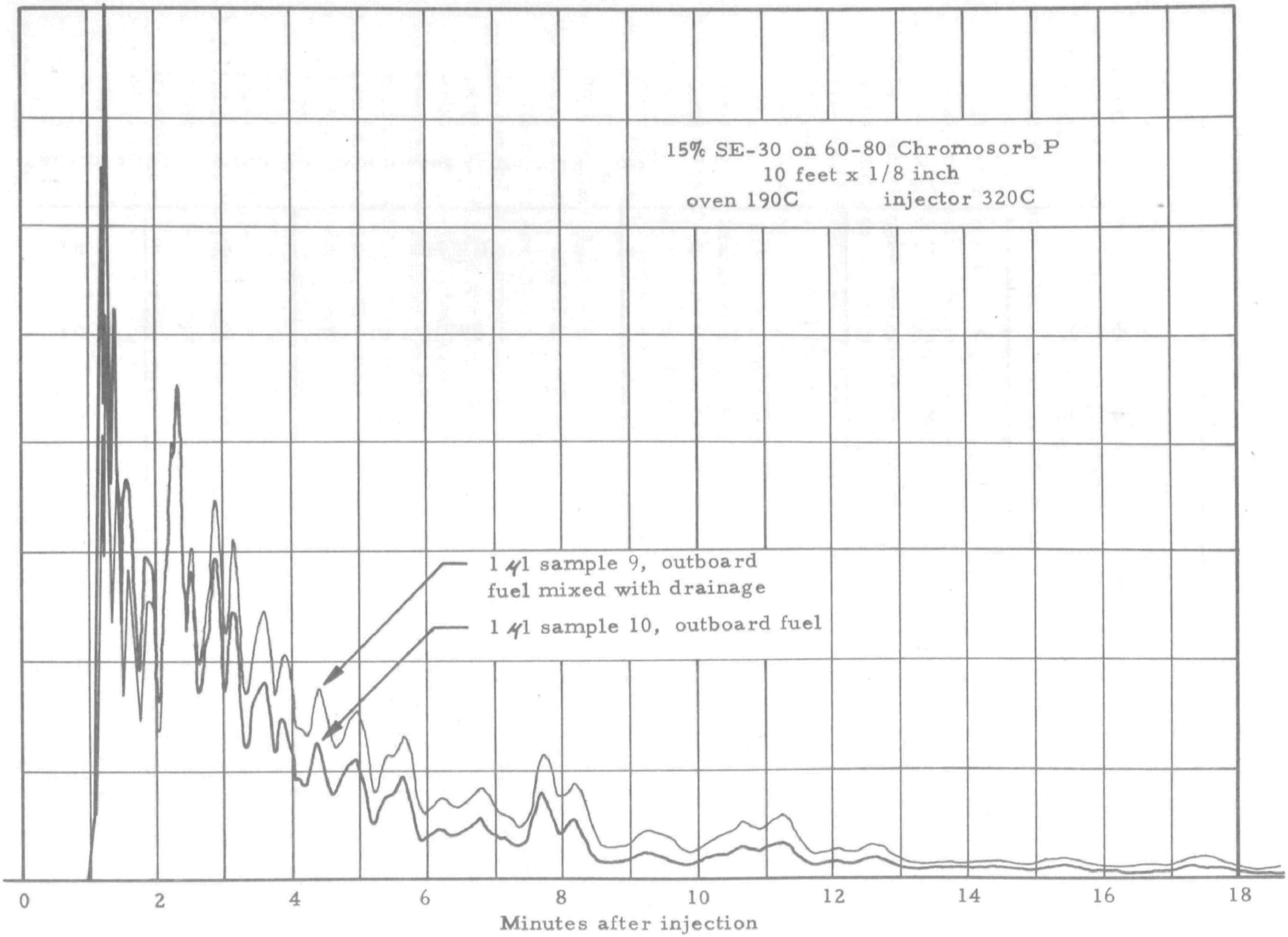

Figure 48. Chromatogram (tracing) of outboard fuel and fuel mixed with drainage

As another comment on the characteristics of the fuels and oils being discussed, Table 13 has been prepared to show the boiling ranges of the materials. Note that the gasoline boiling range overlaps the "dilution components of the oil, which come out between 325°and 440°F (data show relatively rapid evaporation between these temperatures, especially between 325°and 352°F, then a relatively slow evaporation until the high-lubricity components start to come over strongly at about 650°F).

Table 13. BOILING RANGES OF THE OUTBOARD GASOLINE AND ONE OF THE OILS USED IN THE SUBJECT STUDY

	Temperatures, °F	
Distillation	Gasoline	Oil
Initial boiling point	90	325
10%	118	352
20%	---	440
30%	---	650
40%	---	690
50%	206	708
60%	---	719
70%	---	730
80%	---	739
90%	320	750
95%	---	755
End point	404	758

The major importance of the chromatographic study is that it shows the shift toward lower concentrations of light hydrocarbons and higher concentrations of heavier fuel components as drainage is mixed with fresh fuel. Note that the first few peaks (out to a retention time of approximately 2 minutes) are lower for sample No. 9 (fuel-drainage mixture) than for sample 10 (fuel only). From 2 minutes retention time on, concentrations of heavier materials are higher for sample No. 9. The shift toward higher molecular weight components for fuel mixed with drainage means that its physical characteristics change: volatility decreases, viscosity increases, and density increases. The impact of these changes on engine performance is not within the scope of the subject work, and further research would have to be done before definite conclusions could be reached.

SECTION VII

ESTIMATE OF (QUANTITATIVE) NATIONAL IMPACT OF OUTBOARD MOTOR CRANKCASE DRAINAGE EMISSIONS

Accuracy of the estimated total drainage emitted from drain-type outboard motors depends strongly on the operating cycle which is assumed to apply to these motors. Data presented in Tables 2 through 4 were used to determine the cyclic operation used during the drainage measurement phase because no other data were available. The sample of motors from which these data were acquired, however, was not very extensive; so it is not possible to assume that this sample was representative, without statistical bias, of the real motor population's average usage. A valid statistical sample from which an estimate could be made of average usage to apply to the world population might require a survey of as many as 1000 engines or more. The survey would require representation based on such things as size of engine, age of engine, size of boat, type of boat, age of owner, type of waters on which boating occurs, climatic conditions, geographical area, and so forth.

Rather than rely on the survey data presented in Tables 2 through 4 (and consequently on the drainage emissions measured during cyclic operation in the testing phase) to estimate national drainage emissions, it is considered more appropriate to apply arbitrary time-based weighting factors to drainage measured during the five steady-state modes. While this method gives no greater assurance of accuracy in estimating drainage emissions than the use of measurements obtained during "cycles" does, it at least provides a convenient way of updating the results of this report in the future when truly representative boat operating data become available. It will be assumed, therefore, that the five modes are used equally (that is, each mode has a time weight of 20 percent).

Applying this assumption to the data on individual modes given in Table 8 results in the drainage and fuel consumption figures shown in Table 14. These calculated data exhibit variability very similar to those measured during cycles and reported earlier, but the calculated composite percentages are all somewhat higher than those measured during the cycles (average difference about 30 percent of percentage measured during cycle). The calculated composites are adequate for use in the subject analysis, and the only alternative is use of time-in-mode data that would require a survey of a large number of engines as indicated above. Such an effort on gathering time-in-mode data is beyond the scope of this research effort.

Accuracy of the analysis used to estimate drainage emissions from the U. S.

Table 14. COMPOSITE FUEL CONSUMPTION AND DRAINAGE RATES FOR TEST ENGINES ASSUMING EQUAL TIME IN EACH STEADY-STATE MODE

Group no.	Group	Motor No.	Drain rate, g/hr	Fuel rate, kg/hr	Drainage as % of fuel
1	OMC 9.5 hp twins	1	141.7	3.36	4.21
		24[a]	95.4	2.57	3.71
		27[a]	286.0	3.12	9.15
		28	284.8	3.01	9.45
		34	250.9	2.97	8.45
		35	140.5	2.92	4.82
2	OMC V-4 motors	10	488.8	12.15	4.02
		15	1748.0	10.75	16.26
		15A	794.4	9.26	8.58
		18	1179.0	12.94	9.11
		22	990.4	11.02	8.99
3	OMC 30-40 hp twins	3	190.6	5.85	3.26
		8	115.0	6.60	1.74
		13	247.1	6.13	4.03
		33	41.9	5.14	0.82
4	Chrysler and Sea King 35-55 hp twins	6	62.4	8.48	0.74
		11	46.5	8.09	0.57
		19	3.4	7.54	0.04
		20	70.6	6.55	1.08
		32	7.8	6.22	0.12
5	Mercury 4- and 6-cylinder motors	4	48.8	9.85	0.50
		7	14.6	6.20	0.24
		14	84.3	11.64	0.72
		16	45.3	9.99	0.45
		17	58.2	9.85	0.59
6	OMC twins using pressure tank (older)	5	56.4	3.63	1.55
		12	161.1	5.18	3.11
		21	15.4	8.14	0.19
7	OMC 18 hp twins	2	92.1	3.98	2.31
		31[a]	58.7	3.99	1.47
	Miscellaneous	23	127.7	1.57	8.12
		30[a]	43.8	1.66	2.64

[a] Originally drainless engine converted to drained configuration for tests.

population of outboards depends on certain assumptions about that population. The simplest situation would result from the assumption that drain percentages are distributed normally for the population taken as a whole; but this assumption requires implicitly that mean drain percentages from Mercury, Chrysler, and OMC engines all be essentially equal. To test the hypothesis that mean drainage rates are equal for the Chrysler, Mercury, and OMC populations, the "t" statistic (Student's distribution) was used. The results showed that the hypothesis could be accepted for the Chrysler and Mercury populations at the 0.05 level, but that the hypothesis should be rejected at the 0.05 level for the OMC population as compared to the other two. Testing of a hypothesis at the 0.05 level is a matter of convention, and rejection at the 0.05 level indicates that the chance of the hypothesis being correct is 5% or less. Student's "t" test also showed that the hypothesis of equal means could be accepted for the Chrysler and Mercury populations all the way up to the 0.4 (or 40 percent probability) level, but that the same hypothesis had to be rejected for the OMC population as compared to the other two even at the 0.01 (or 1 percent probability) level. The results at these widely-dispersed levels indicate that the difference in mean composite drain percentage between Mercury and Chrysler engines tested is very insignificant, and that the difference in mean drainage between the Chrysler-Mercury group and the OMC group is highly significant. These statistical tests indicate that outboard motor drainage cannot be analyzed statistically for the population of motors as a whole, but that the OMC and non-OMC populations should be considered separately. Calculation of the "t" statistics discussed above is presented in Appendix C.

Arithmetic means of the composite drain percentages listed in Table 14 are 5.35 percent for OMC motors and 1.20 percent for non-OMC motors. Due to the small samples and the large variations within the samples, it cannot be assumed that the sample drainage means are equal to population means. It is possible, however, to determine statistically from such samples a range within which the population mean drainage can be expected to occur with, for instance, 95% confidence. The formula for the extremes of the range is

$$\text{confidence limits} = \bar{x} \pm t_{0.975} (S_{\bar{x}}),$$

where: $\bar{x}$ = sample mean drainage;

$t_{0.975}$ = the appropriate statistic from Student's distribution at the 0.05 level of significance; and

$S_{\bar{x}}$ = standard error of the sample mean.

Using this formula, the mean drainage from the OMC population is estimated (with 95% confidence) to fall within the range of 3.19 to 7.51

percent of fuel consumed by weight. Average drainage from the non-OMC population is likewise estimated to be between 0 and 2.76 percent. A summary of the statistics leading to these confidence limits is given in Table 15.

Table 15. DETERMINATION OF 95% CONFIDENCE LIMITS ON MEAN DRAINAGE FOR OMC AND NON-OMC POPULATIONS

Population	n = sample size	drainage (percent)		$t_{0.975}$	95% conf. limits on pop. drainage
		$\bar{x}$ = mean	$S_{\bar{x}}$ = std. error		
OMC	17	5.35	1.02	2.12	3.19 - 7.51%
non-OMC	11	1.20	0.70	2.23	0 - 2.76%

In order to estimate the total amount of drainage emitted per year by drained engines, it is necessary to establish a figure for the total fuel they consume. One method would be to simply accept an estimate made by a boating trade publication(21) or one of several individuals in the industry(22-24). These estimates are of unknown accuracy and basis, however, so a fuel consumption figure will be calculated here using available data and explicit assumptions. While this calculation is subject to errors, detailing the method and assumptions will permit its correction if more complete data become available in the future.

Using data from Table 14, fuel consumed by each engine per hour per unit rated horsepower can be calculated (based on the assumed composite cycle). The results of these calculations are grouped in Table 16 by motor rated horsepower category, along with population data and further calculated values. The "mean" rated horsepower assumed for the three lower power categories is the same as that used in an earlier analysis of outboard motor exhaust (gaseous) emissions(25), and the "mean" value for the "45 hp and over" category has been adjusted downward slightly to improve accuracy. The previous estimate of 65 hp for the larger motors resulted in a calculated population mean of 25.8 hp, and the 60 hp estimate used here changes that result to 24.8 hp, nearer the best available figure (24.6 hp). The population being considered here is for 1971, the last year in which drained engines were produced,and Table 17 gives a summary of the estimated motor population for that year by power category and year of manufacture. The total annual fuel consumption by drained engines calculated by this analysis is about 600 million gallons per year (1660 million kg/yr), and this figure will be used to estimate drainage emissions.

Table 16. CALCULATION OF OUTBOARD MOTOR FUEL CONSUMPTION (BASED ON 1971 MOTOR POPULATION)

Power category, hp	Category population x 10^{-3}	Assumed "mean" rated hp	Fuel consumption				
			g per rated hp hr	g per engine hr	kg per engine yr[a]	gal per engine yr[b]	category gal per yr x 10^{-3}
0-6.9	2303.	5	247	1230.	61.8	22.3	51,400.
7-19.9	1990.	15	274	4110.	206.	74.2	148,000.
20-44.9	1648.	35	194	6790.	340.	123.	202,000.
45 & over	1377.	60	149	8940.	447.	161.	200,000.[c]
						TOTAL	601,000.

[a] Assuming 50 hr operation per year.

[b] Assuming fuel density of 6.1 lb_m/gal (0.73 kg/l).

[c] Assuming that 10 percent of engines in this category were drainless.

Table 17. SUMMARY OF ESTIMATED OUTBOARD MOTOR POPULATION BY POWER CATEGORY AND AGE, END OF 1971

	Surviving Motors in Horsepower Category $\times 10^{-3}$			
Year(s)	0-6.9	7.0-19.9	20.0-44.9	45 & up
1919-1930	0.793			
1931-1941	24.2			
1946	68.1			
1947	114.			
1948	112.			
1949	71.9	11.7		
1950	85.0	20.0		
1951	55.8	35.6		
1952	84.7	31.5	4.84	
1953	126.	44.4	14.8	
1954	124.	61.2	25.3	
1955	90.0	120.	30.0	10.0
1956	91.8	160.	66.3	22.1
1957	69.5	133.	85.3	28.4
1958	53.0	125.	101.	33.5
1959	61.0	122.	132.	44.0
1960	53.1	89.6	142.	47.3
1961	44.0	64.8	101.	49.2
1962	48.6	71.5	109.	57.2
1963	57.4	72.5	106.	66.4
1964	71.4	85.0	102.	81.6
1965	67.4	135.	67.4	85.2
1966	102.	123.	86.1	98.4
1967	119.	97.5	93.3	114.
1968	142.	102.	102.	142.
1969	141.	95.8	95.8	171.
1970	116.	94.4	90.1	129.
1971	109.	94.0	94.0	198.
Total	2303.	1990.	1648.	1377.

In order to estimate total drainage, making use of the ranges of values developed earlier for OMC and non-OMC populations, it remains to determine the number of engines falling into each group. The only study yielding such results for even a small area(18) shows that OMC units comprised about 55 percent of the population sampled at Lake George, New York. Using this figure as basis, a range of estimates can be made as shown in Table 18. To indicate the influence of population composition on drainage, another set of estimates is also given in Table 18 using a population containing 70 percent OMC engines. This latter assumption is arbitrary, and not based on any known population composition. Note that total annual drainage estimates in gallons were calculated using volume percentages and that volume percentages are about 87 percent of weight percentages because drainage is more dense than fuel.

Based on all the assumptions noted during the calculations, the overall drainage estimate for the "55 percent OMC" assumption is between 1.8 and 5.4 percent of fuel consumed on a weight basis for 95 percent confidence. These percentages translate into a range of 9.2 to 28 million gallons per year (29 to 89 million kg/yr). For the "70 percent OMC" assumption, the population drainage estimate is between 2.2 and 6.1 percent of fuel consumed on a weight basis for 95 percent confidence. These figures can be otherwise expressed as a range of 12 to 32 million gallons per year or 37 to 101 million kg per year.

ENVIRONMENTAL IMPACT

It was not the purpose of this study to determine the environmental impact of drainage on aquatic systems, but only to estimate the amount of drainage. Other projects have been funded by the Environmental Protection Agency to study the environmental effects of drainage. Care should be exercised in applying the results of this study to specific situations, especially use of "average" values. As an example, consider inlets, marina areas, protected harbors, and areas where trolling occurs. These locations will be subject to more engine operation at low speeds than was assumed to form the composite operating schedule, so drainage emitted there will be higher on a percentage basis than indicated by average values.

For idle and low-speed operation (1500 rpm and under), it can be computed from data in Table 9 that average drainage for the OMC's tested would be 17.2 percent (standard error = 2.84) and that for non-OMC's would be 3.0 percent (standard error = 0.73). It can also be calculated (using the "t" distribution) that the 95 percent confidence interval for mean drainage from the OMC population is 11.2 to 23.3 percent, and that the similar interval for the non-OMC population is 1.37 to 4.63 percent

Table 18. ESTIMATES OF TOTAL ANNUAL OUTBOARD MOTOR CRANKCASE DRAINAGE EMISSIONS AND PERCENTAGES OF FUEL CONSUMED

			Assumption 1			Assumption 2		
			OMC	non-OMC	Total	OMC	non-OMC	Total
Population breakdown, %			55	45	100	70	30	100
[a]Annual fuel Consumption		gal x 10^{-6}	330.	270.	600.	420.	180.	600.
		kg x 10^{-6}	913.	747.	1660.	1160.	498.	1660.
Drain percentages (by weight)	High		7.51	2.76	5.37	7.51	2.76	6.08
	Low		3.19	0	1.75	3.19	0	2.23
Drain percentages (by volume)	High		6.54	2.40	4.68	6.54	2.40	5.30
	Low		2.78	0	1.53	2.78	0	1.95
Total annual drainage	High	gal x 10^{-6}	21.6	6.48	28.1	27.5	4.32	31.8
		kg x 10^{-6}	68.6	20.6	89.2	87.3	13.7	101.
	Low	gal x 10^{-6}	9.17	0	9.17	11.7	0	11.7
		kg x 10^{-6}	29.1	0	29.1	37.1	0	37.1

[a] assuming that fuel consumption is directly proportional to population percentage.

Note: Specific gravity of drainage averaged 0.84 compared to specific of fuel of 0.73; therefore, drain percentage by volume is 87 percent of drain percentage by weight.

by weight of fuel consumed. Calculation of these intervals is given in Appendix C.

Using data from Tables 8 and 18, it can be calculated that the amount of fuel consumed annually by OMC engines at idle and low speeds (1500 rpm and under) is about 20% of their total annual fuel consumption, or approximately 66 million gallons. Comparable figures for non-OMC engines are about 16% of fuel consumed at 1500 rpm or lower speeds, and a total of approximately 44 million gallons. Using these fuel consumption figures and the ranges for drainage estimated above, OMC engines are estimated to emit 6.4 to 13.1 million gallons of drainage annually at speeds of 1500 rpm or lower, and non-OMC engines are estimated to emit 0.5 to 1.8 million gallons per year during this type of operation. Total drainage at speeds of 1500 rpm and lower, consequently, is estimated at 7 to 15 million gallons per year. These figures indicate that idle and low speed drainage accounts for between 50 and 75 percent of total drainage from outboards.

SECTION VIII

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SECTION IX

APPENDIX A

Comprehensive Test Data

TEST ENGINE NO. 1 TYPE 1965 JOHNSON 9.5 hp

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	lbm	gal	min	lbm/hr	gal/hr	g	ml	VOL.	WT.	g/hr
1	IDLE	1.30	0.207	20	3.90	0.620	62.4	77.0	9.83	10.6	187.
2	1500	1.75	0.278	20	5.25	0.835	87.1	106.2	10.1	11.0	261.
3	2750	1.75	0.278	15	7.00	1.11	45.7	56.0	5.32	5.76	183.
4	4000	1.50	0.238	10	9.00	1.43	5.0	7.3	0.810	0.735	30.0
5	*4700	1.75	0.278	10	10.50	1.67	12.5	16.0	1.52	1.57	75.0
6	IDLE	1.20	0.191	20	3.60	0.572	67.3	82.0	11.3	12.4	202.
7	1500	1.30	0.207	20	3.90	0.620	82.7	101.0	12.9	14.0	248.
8	2750	2.05	0.326	15	8.20	1.30	43.5	53.0	4.29	4.68	174.
9	4000	1.85	0.294	10	11.10	1.76	2.4	2.8	0.252	0.286	14.4
10	*4700	1.95	0.310	10	11.70	1.86	7.6	10.5	0.895	0.859	45.6
11	CYCLE	2.35	0.374	20	7.05	1.12	26.0	32.0	2.26	2.44	78.0
12	CYCLE	2.75	0.437	20	8.25	1.31	32.8	39.5	2.39	2.63	98.4

FUEL TEMP. AT ENGINE ≅ 60 °F DENSITY = 6.29 lbm/gal (60°F)

FUEL DENSITY AT 72°F = 6.25 lbm/gal = 0.748 g/ml

COMMENTS * TOP RPM ; TESTED AFTER TUNING ONLY ; ENGINE IDLED AT 1000 RPM ; FUEL:OIL RATIO 50:1

TEST ENGINE NO. 2 TYPE 1960 EVINRUDE 18hp

RUN	CONDITION	FUEL USED		TIME,	FUEL RATE		SAMPLE(72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
		lb$_m$	gal	min	lb$_m$/hr	gal/hr	g	ml	VOL.	WT.	g/hr
1	IDLE	0.80	0.130	20	2.40	0.390	33.8	39.5	8.03	9.30	101.
2	1500	1.45	0.236	20	4.35	0.707	52.3	62.0	6.95	7.95	157.
3	3000	2.45	0.398	15	9.80	1.59	28.0	33.0	2.19	2.52	112.
4	4000	2.20	0.357	10	13.20	2.14	4.7	5.2	0.384	0.470	28.2
5	4500	2.45	0.398	10	14.70	2.39	2.6	2.9	0.193	0.234	15.6
6	IDLE	0.60	0.0975	20	1.80	0.292	18.1	21.5	5.83	6.64	54.3
7	1500	1.50	0.244	20	4.50	0.731	22.3	26.5	2.87	3.28	66.9
8	3000	2.10	0.341	15	8.40	1.36	13.2	16.0	1.24	1.38	52.8
9	4000	1.75	0.284	10	10.50	1.71	2.7	2.9	0.270	0.340	16.2
10	4500	2.00	0.325	10	12.00	1.95	2.2	2.3	0.187	0.242	13.2
11	CYCLE	3.25	0.528	20	9.75	1.58	16.4	19.5	0.976	1.11	49.2
12	CYCLE	3.30	0.536	20	9.90	1.61	22.6	27.5	1.35	1.51	67.8
13	IDLE	1.10	0.179	20	3.30	0.536	85.9	102.	15.1	17.2	258.
14	1500	1.95	0.317	20	5.85	0.950	91.7	109.	9.09	10.4	275.
15	3000	2.45	0.398	15	9.80	1.59	17.3	20.5	1.36	1.56	69.2
16	4000	2.15	0.349	10	12.90	2.10	3.6	4.3	0.325	0.369	21.6
17	4500	2.45	0.398	10	14.70	2.39	3.5	3.5	0.232	0.315	21.0
18	IDLE	1.20	0.195	20	3.60	0.585	71.1	84.0	11.4	13.1	213.
19	1500	1.90	0.309	20	5.70	0.926	82.1	98.0	8.39	9.53	246.
20	3000	2.60	0.422	15	10.40	1.69	18.4	21.0	1.31	1.56	73.6
21	4000	2.25	0.365	10	13.50	2.19	4.3	5.1	0.369	0.421	25.8
22	4500	2.45	0.398	10	14.70	2.39	3.5	3.9	0.259	0.315	21.0
23	CYCLE	3.60	0.585	20	10.80	1.75	28.7	34.0	1.54	1.76	86.1
24	CYCLE	3.70	0.601	20	11.10	1.80	31.5	37.0	1.63	1.88	94.5

FUEL TEMP. AT ENGINE ≅ 90 °F DENSITY = 6.157 lb$_m$/gal (90°F)

FUEL DENSITY AT 72°F = 6.215 lb$_m$/gal = 0.745 g/ml

COMMENTS ENGINE RAN ROUGHLY AT IDLE AND 1500 BEFORE TUNING; LOW SPEED JET RICHENED SOMEWHAT AFTER TUNING; FUEL:OIL RATIO 24:1 ; ENGINE IDLED AT 800 RPM; TUNED AFTER RUN 12

TEST ENGINE No. 3 TYPE 1966 JOHNSON 33 hp

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	lb_m	gal	min	lb_m/hr	gal/hr	g	ml	VOL.	WT.	g / hr
1	IDLE	1.15	0.186	20	3.45	0.558	130.3	156.	22.2	25.0	391.
2	1500	2.05	0.332	20	6.15	0.995	139.9	167.	13.3	15.0	420.
3	3000	2.80	0.453	15	11.20	1.81	27.0	32.0	1.87	2.13	108.
4	4500	3.25	0.526	10	19.50	3.15	9.0	10.5	0.528	0.611	54.0
5	4800	3.65	0.590	10	21.90	3.54	11.8	14.1	0.631	0.713	70.8
6	IDLE	1.35	0.218	20	4.05	0.655	153.9	184.	22.3	25.1	462.
7	1500	2.05	0.332	20	6.15	0.995	78.5	93.5	7.44	8.44	236.
8	3000	2.70	0.437	15	10.80	1.75	16.3	19.5	1.18	1.33	65.2
9	4500	3.05	0.493	10	18.30	2.96	8.6	10.2	0.546	0.622	51.6
10	4800	3.65	0.590	10	21.90	3.54	10.4	12.1	0.542	0.628	62.4
11	CYCLE	4.60	0.744	20	13.80	2.23	40.5	48.0	1.70	1.94	122.
12	CYCLE	4.35	0.704	20	13.05	2.11	36.9	44.5	1.67	1.87	111.
13	IDLE	1.60	0.259	20	4.80	0.776	159.6	192.	19.6	22.0	479.
14	1500	2.35	0.380	20	7.05	1.14	92.7	112.	7.78	8.70	278.
15	3000	3.05	0.493	15	12.20	1.97	27.2	33.0	1.77	1.97	109.
16	4500	3.75	0.607	10	22.50	3.64	10.4	15.0	0.653	0.611	62.4
17	4800	4.00	0.647	10	24.00	3.88	12.2	17.0	0.694	0.672	73.2
18	IDLE	1.15	0.186	20	3.45	0.558	142.5	172.	24.4	27.3	428.
19	1500	2.10	0.340	20	6.30	1.02	80.6	96.5	7.51	8.46	242.
20	3000	2.80	0.453	15	11.20	1.81	24.7	30.0	1.75	1.94	98.8
21	4500	3.50	0.566	10	21.00	3.40	8.9	13.5	0.630	0.561	53.4
22	4800	3.70	0.598	10	22.20	3.59	11.3	14.0	0.618	0.673	67.8
23	CYCLE	4.85	0.784	20	14.55	2.35	36.3	43.5	1.46	1.65	109.
24	CYCLE	4.95	0.801	20	14.85	2.40	41.0	49.0	1.62	1.83	123.

FUEL TEMP. AT ENGINE ≅ 90 °F DENSITY = 6.183 lb_m/gal (90°F)

FUEL DENSITY AT 72°F = 6.242 lb_m/gal = 0.748 g/ml

COMMENTS FUEL : OIL RATIO WAS 50 : 1 ; 4800 WAS MAX. RPM BEFORE AND AFTER TUNING ; CARBURETOR AND TIMING OK AS RECEIVED ; IDLE RPM WAS 700 BEFORE TUNING, 800 AFTER ; TUNED AFTER RUN 12

TEST ENGINE NO. 4 TYPE 1965 MERCURY 65 hp

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F) ← ONE DRAIN ONLY		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	lb_m	gal	min	lb_m/hr	gal/hr	g	ml	VOL.	WT.	g / hr *
1	IDLE	1.90	0.308	20	5.70	0.925	8.3	10.0	0.856	0.963	49.8
2	1500	4.45	0.723	20	13.4	2.17	11.3	14.0	0.512	0.560	67.8
3	2750	6.10	0.990	15	24.4	3.96	12.0	14.5	0.387	0.434	96.0
4	4250	5.45	0.885	10	32.7	5.31	1.5	1.9	0.057	0.061	18.0
5	IDLE	1.50	0.244	20	4.50	0.731	5.4	7.0	0.758	0.794	32.4
6	1500	4.55	0.739	20	13.6	2.22	10.9	13.0	0.465	0.528	65.4
7	2750	6.25	1.01	15	25.0	4.06	12.2	14.5	0.379	0.430	97.6
8	4250	5.40	0.877	10	32.4	5.26	1.8	2.3	0.069	0.073	21.6
9	CYCLE	8.60	1.40	20	25.8	4.19	10.6	12.5	0.236	0.272	63.6
10	CYCLE	8.65	1.40	20	26.0	4.21	9.8	12.0	0.226	0.250	58.8

FUEL TEMP. AT ENGINE ≅ 90 °F DENSITY = 6.159 lb_m/gal (90°F)

FUEL DENSITY AT 72°F = 6.217 lb_m/gal = 0.745 g/ml

COMMENTS * SAMPLE RATE SHOWN IS DOUBLE THAT COLLECTED, SINCE ONLY ONE OF TWO DRAINS WAS INTERCEPTED; FUEL : OIL RATIO 50:1; ENGINE IDLED AT 700 RPM; ENGINE WOULD NOT RUN SATISFACTORILY AS RECEIVED, SO WAS TESTED AFTER MINOR TUNE ONLY; MAX. RPM 4500

TEST ENGINE NO. 5 TYPE 1954 EVINRUDE 15 hp

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	lb$_m$	gal	min	lb$_m$/hr	gal/hr	g	ml	VOL.	WT.	g/hr
1	IDLE	1.1	0.18	20	3.3	0.54	14.6	18.0	2.64	2.93	43.8
2	1500	1.2	0.20	20	3.6	0.60	25.2	30.0	3.96	4.63	75.6
3	3000	1.8	0.29	15	7.2	1.16	6.4	8.5	0.774	0.784	25.6
4	4000	1.8	0.29	10	10.8	1.74	5.0	7.5	0.683	0.612	30.0
5	4500	2.5	0.41	10	15.0	2.46	7.8	10.0	0.644	0.688	46.8
6	IDLE	1.0	0.16	20	3.0	0.48	18.1	22.0	3.63	3.99	54.3
7	1500	1.2	0.20	20	3.6	0.50	27.9	33.5	4.42	5.13	83.7
8	3000	2.0	0.33	15	8.0	1.32	5.5	7.5	0.600	0.606	22.0
9	4000	1.9	0.31	10	11.4	1.86	5.0	7.0	0.596	0.580	30.0
10	4500	2.3	0.37	10	13.8	2.22	7.6	10.0	0.714	0.728	45.6
11	CYCLE	2.6	0.42	20	7.8	1.26	17.2	21.0	1.32	1.46	51.6
12	CYCLE	2.7	0.44	20	8.1	1.32	18.6	22.0	1.32	1.52	55.8
13	IDLE	1.1	0.18	20	3.3	0.54	26.3	31.0	4.55	5.27	78.9
14	1500	1.3	0.21	20	3.9	0.63	45.9	53.5	6.73	7.78	138.
15	3000	2.5	0.41	15	10.0	1.64	11.7	14.0	0.902	1.03	46.8
16	4000	1.9	0.31	10	11.4	1.86	9.1	11.0	0.937	1.06	54.6
17	4500	2.1	0.34	10	12.6	2.04	10.0	12.0	0.932	1.05	60.0
18	IDLE	1.1	0.18	20	3.3	0.54	23.2	27.5	4.04	4.65	69.6
19	1500	1.2	0.20	20	3.6	0.60	37.0	43.0	5.68	6.80	111.
20	3000	24	0.39	15	9.6	1.56	7.8	10.0	0.677	0.716	31.2
21	4000	1.8	0.29	10	10.8	1.74	5.6	6.5	0.592	0.686	33.6
22	4500	2.0	0.33	10	12.0	1.98	8.1	9.4	0.752	0.893	48.6
23	CYCLE	2.9	0.47	20	8.7	1.41	15.9	19.0	1.07	1.21	47.7
24	CYCLE	2.7	0.44	20	8.1	1.32	21.1	25.0	1.50	1.72	63.3

FUEL TEMP. AT ENGINE ≅ 90 °F DENSITY = 6.151 lb$_m$/gal (90°F)

FUEL DENSITY AT 72°F = 6.209 lb$_m$/gal = 0.744 g/ml

COMMENTS FUEL:OIL RATIO 24:1 ; ENGINE IDLED AT 1000 RPM ; TUNED AFTER RUN 12 ; RICHENED BOTH LOW- AND HIGH-SPEED JETS SOMEWHAT AFTER TUNING ; USED PRESSURE-TYPE TANK

TEST ENGINE NO. 6 TYPE 1965 SEA KING (WEST BEND) 50 hp

RUN	CONDITION	FUEL USED lbm	gal	TIME, min	FUEL RATE lbm/hr	gal/hr	SAMPLE (72°F) g	ml	SAMPLE % OF FUEL BY VOL.	WT.	SAMPLE RATE, g/hr
1	IDLE	0.95	0.155	20	2.85	0.465	78.6	93.0	15.9	18.2	236.
2	1500	2.05	0.334	20	6.15	1.00	7.7	9.1	0.720	0.828	23.1
3	2750	3.85	0.627	15	15.4	2.51	2.0	2.4	0.101	0.115	8.0
4	4250	4.80	0.782	10	28.8	4.69	1.0	1.2	0.040	0.046	6.0
5	4750	6.65	1.08	10	39.9	6.48	2.1	2.5	0.061	0.070	12.6
6	IDLE	1.45	0.236	20	4.35	0.708	94.7	113.	12.6	14.4	284.
7	1500	2.20	0.358	20	6.60	1.08	3.8	4.4	0.324	0.381	11.4
8	2750	4.05	0.660	15	16.2	2.64	1.2	1.4	0.056	0.065	4.8
9	4250	4.70	0.765	10	28.2	4.59	0.8	1.0	0.034	0.038	4.8
10	4750	6.65	1.08	10	39.9	6.48	1.9	2.4	0.059	0.063	11.4
11	CYCLE	5.40	0.879	20	16.2	2.64	11.0	13.5	0.406	0.449	33.0
12	CYCLE	5.60	0.912	20	16.8	2.74	19.5	23.5	0.681	0.768	58.5
13	IDLE	1.10	0.179	20	3.30	0.537	112.6	134.	19.8	22.6	338.
14	1200	2.05	0.334	20	6.15	1.00	79.6	95.5	7.55	8.56	239.
15	1500	1.55	0.252	15	6.20	1.01	2.7	3.4	0.356	0.384	10.8
16	2750	2.60	0.423	10	15.6	2.54	0.5	0.4	0.025	0.042	3.0
17	4250	4.85	0.790	10	29.1	4.74	1.8	2.0	0.067	0.082	10.8
18	IDLE	0.75	0.122	20	2.25	0.366	80.4	94.5	20.5	23.6	241.
19	1200	2.25	0.366	20	6.75	1.10	56.4	67.0	4.84	5.53	169.
20	1500	1.45	0.236	15	5.80	0.944	2.5	3.1	0.347	0.380	10.0
21	2750	2.65	0.432	10	15.9	2.59	0.3	0.2	0.012	0.025	1.8
22	4250	4.65	0.757	10	27.9	4.54	1.1	1.4	0.049	0.052	6.6
23	CYCLE	5.65	0.920	20	17.0	2.76	18.2	22.0	0.632	0.710	54.6
24	CYCLE	5.70	0.928	20	17.1	2.78	26.0	30.5	0.868	1.01	78.0

FUEL TEMP. AT ENGINE ≅ 90 °F DENSITY = 6.141 lbm/gal (90°F)

FUEL DENSITY AT 72°F = 6.199 lbm/gal = 0.743 g/ml

COMMENTS FUEL:OIL RATIO 50:1 ; ENGINE IDLED AT 900 RPM ; ENGINE RAN SOMEWHAT ROUGHLY AT IDLE AS RECEIVED ; NO CARBURETOR ADJUSTMENTS NECESSARY ; TUNED AFTER RUN 12

TEST ENGINE NO. 7 TYPE 1959 MERCURY MARK 58A 45 hp

← ONE DRAIN ONLY →

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	lb_m	gal	min	lb_m/hr	gal/hr	g	ml	VOL.	WT.	g / hr *
1	IDLE	2.05	0.331	20	6.15	0.993	3.0	3.5	0.279	0.323	18.0
2	1500	2.05	0.331	20	6.15	0.993	3.3	3.6	0.287	0.355	19.8
3	2750	3.65	0.589	15	14.60	2.36	2.9	3.4	0.152	0.175	23.2
4	4250	3.05	0.492	10	18.30	2.95	1.0	1.2	0.064	0.072	12.0
5	5000	3.90	0.629	10	23.40	3.77	0.7	0.4	0.017	0.040	8.4
6	IDLE	1.60	0.258	20	4.80	0.774	2.8	3.4	0.348	0.386	16.8
7	1500	2.25	0.363	20	6.75	1.09	1.8	2.2	0.160	0.176	10.8
8	2750	3.75	0.605	15	15.00	2.42	3.4	4.0	0.175	0.200	27.2
9	4250	2.85	0.460	10	17.10	2.76	1.1	1.4	0.080	0.085	13.2
10	5000	4.35	0.701	10	26.10	4.21	0.6	0.5	0.019	0.030	7.2
11	CYCLE	4.40	0.709	20	13.20	2.13	2.0	2.1	0.078	0.100	12.0
12	CYCLE	4.40	0.709	20	13.20	2.13	2.5	2.7	0.101	0.125	15.0
13	IDLE	1.50	0.242	20	4.50	0.726	3.6	4.1	0.448	0.529	21.6
14	1500	2.20	0.355	20	6.60	1.06	2.3	2.9	0.216	0.230	13.8
15	2750	3.60	0.580	15	14.40	2.32	2.1	2.5	0.114	0.129	16.8
16	4250	3.10	0.500	10	18.60	3.00	0.5	0.6	0.032	0.036	6.0
17	5000	3.75	0.605	10	22.50	3.63	0.4	0.5	0.022	0.024	4.8
18	CYCLE	4.25	0.685	20	12.75	2.06	1.6	1.9	0.073	0.083	9.6

FUEL TEMP. AT ENGINE ≅ 90 °F DENSITY = 6.144 lb_m/gal (90°F)

FUEL DENSITY AT 72°F = 6.202 lb_m/gal = 0.743 g/ml

COMMENTS ENGINE RAN WELL BEFORE AND AFTER TUNING; ENGINE IDLED AT 1000 RPM; TUNED AFTER RUN 12; NO CARBURETOR ADJUSTMENT; FUEL : OIL RATIO 50:1; *SEE ENGINE 4 DATA SHEET

TEST ENGINE NO. 8 TYPE 1968 JOHNSON 40 hp

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	lb_m	gal	min	lb_m/hr	gal/hr	g	ml	VOL.	WT.	g / hr
1	IDLE	1.70	0.276	20	5.10	0.828	119.8	140.5	13.4	15.5	359.
2	1500	2.25	0.365	20	6.75	1.10	51.7	60.0	4.34	5.07	155.
3	3000	3.05	0.495	15	12.20	1.98	11.1	13.5	0.720	0.802	44.4
4	4300	3.95	0.641	10	23.70	3.85	6.2	8.0	0.330	0.346	37.2
5	IDLE	1.70	0.276	20	5.10	0.828	113.7	133.5	12.8	14.7	341.
6	1500	2.30	0.373	20	6.90	1.12	48.2	57.5	4.07	4.62	145.
7	3000	2.90	0.471	15	11.60	1.88	8.0	10.0	0.561	0.608	32.0
8	4300	4.15	0.674	10	24.90	4.04	6.2	8.0	0.314	0.329	37.2
9	CYCLE	5.35	0.868	20	16.05	2.60	27.1	32.0	0.974	1.12	81.3
10	CYCLE	5.35	0.868	20	16.05	2.60	27.3	32.5	0.989	1.12	81.9
11	IDLE	1.75	0.284	20	5.25	0.852	97.9	114.5	10.7	12.3	294.
12	1500	2.45	0.398	20	7.35	1.19	43.2	51.0	3.39	3.89	130.
13	3000	2.75	0.446	15	11.00	1.79	7.3	8.5	0.503	0.585	29.2
14	4300	4.10	0.665	10	24.60	3.99	6.1	8.0	0.318	0.328	24.4
15	CYCLE	5.25	0.852	20	15.75	2.56	26.5	31.5	0.977	1.11	79.5

FUEL TEMP. AT ENGINE ≅ 90 °F DENSITY = 6.16 lb_m/gal (90°F)

FUEL DENSITY AT 72°F = 6.220 lb_m/gal = 0.745 g/ml

COMMENTS 4300 WAS TOP RPM; ENGINE IDLED AT 800 RPM; TUNED AFTER RUN 10; FUEL:OIL RATIO 50:1; NO CARBURETOR ADJUSTMENT

TEST ENGINE NO. 9 TYPE 1961 JOHNSON 40 hp

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	lbm	gal	min	lbm/hr	gal/hr	g	ml	VOL.	WT.	g / hr
1	IDLE	2.25	0.364	20	6.75	1.09	114.4	134.0	9.73	11.2	343.
2	1500	3.25	0.525	20	9.75	1.58	151.5	182.0	9.16	10.3	454.
3	3000	4.00	0.646	15	16.00	2.59	54.4	65.0	2.66	3.00	218.
4	4500	3.65	0.590	10	21.90	3.54	13.2	15.5	0.694	0.797	79.2
5	5000	4.75	0.767	10	28.50	4.60	9.6	11.5	0.396	0.446	57.6
6	IDLE	2.50	0.404	20	7.50	1.21	106.6	126.0	8.24	9.40	320.
7	1500	3.10	0.501	20	9.30	1.50	139.9	169.5	8.94	9.95	420.
8	3000	4.45	0.719	15	17.80	2.88	54.0	65.5	2.41	2.68	216.
9	4500	4.10	0.662	10	24.60	3.97	11.0	13.0	0.519	0.591	66.0
10	5000	4.90	0.792	10	29.40	4.75	1.2	1.6	0.053	0.054	7.2
11	CYCLE	5.90	0.953	20	17.70	2.86	59.9	70.5	1.95	2.24	180.
12	CYCLE	6.20	1.00	20	18.60	3.01	66.9	79.5	2.10	2.38	201.
13	IDLE	2.25	0.364	20	6.75	1.09	113.4	134.0	9.73	11.1	340.
*14	1500	2.90	0.469	20	8.70	1.41	134.0	161.5	9.10	10.2	402.
15	3000	4.40	0.711	15	17.60	2.84	54.7	65.0	2.42	2.74	219.
16	4500	3.90	0.630	10	23.40	3.78	12.2	15.0	0.629	0.690	73.2
17	5000	4.85	0.784	10	29.10	4.70	3.5	4.1	0.138	0.159	21.0
18	CYCLE	6.20	1.00	20	18.60	3.01	58.6	69.0	1.82	2.08	176.

FUEL TEMP. AT ENGINE ≅ 90 °F DENSITY = 6.189 lbm/gal (90°F)

FUEL DENSITY AT 72°F = 6.248 lbm/gal = 0.749 g/ml

COMMENTS *WHITE LAYER PRESENT UNDER NORMAL SAMPLE (ABOUT 10 ml) — SEE PHOTO IN TEXT ; ENGINE IDLED AT 1000 RPM ; TUNED AFTER RUN 12 ; FUEL : OIL RATIO 24:1 ; NO CARBURETOR ADJUSTMENT

TEST ENGINE No. 10 TYPE 1967 EVINRUDE 80hp

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	lb_m	gal	min	lb_m/hr	gal/hr	g	ml	VOL.	WT.	g / hr
1	IDLE	4.55	0.739	19	14.37	2.33	442.4	538.0	19.2	21.4	1397.
2	1500	5.70	0.925	20	17.10	2.78	340.4	411.0	11.7	13.2	1021.
3	2750	7.10	1.15	15	28.40	4.61	4.1	4.8	0.110	0.127	16.4
4	4000	5.85	0.950	10	35.10	5.70	24.8	29.5	0.820	0.935	149.
5	5000	8.15	1.32	10	48.90	7.94	51.7	61.5	1.23	1.40	310.
6	IDLE	3.90	0.633	20	11.70	1.90	389.6	465.5	19.4	22.0	1169.
7	1500	4.45	0.722	20	13.35	2.17	270.9	320.5	11.7	13.4	813.
8	2750	5.95	0.966	15	23.80	3.86	22.6	27.0	0.738	0.837	90.4
9	4000	5.75	0.933	10	34.50	5.60	27.6	33.0	0.934	1.06	166.
10	5000	8.20	1.33	10	48.60	7.99	47.9	57.0	1.13	1.29	287.
11	CYCLE	9.15	1.49	20	27.45	4.46	115.5	136.0	2.41	2.78	346.
12	CYCLE	9.30	1.51	20	27.90	4.53	121.5	144.5	2.53	2.88	364.
13	IDLE	3.85	0.625	20	11.55	1.88	360.0	428.0	18.1	20.6	1080.
14	1500	4.75	0.771	20	14.25	2.31	302.5	358.5	12.3	14.0	908.
15	2750	6.75	1.10	15	27.00	4.38	25.8	31.0	0.745	0.843	103.
16	4000	5.85	0.950	10	35.10	5.70	27.2	32.5	0.904	1.03	163.
17	5000	8.00	1.30	10	48.00	7.79	49.6	59.0	1.20	1.37	298.
18	CYCLE	9.10	1.48	20	27.30	4.43	114.2	134.5	2.40	2.77	343.
19	IDLE	3.75	0.609	20	11.25	1.83	383.8	456.5	19.8	22.6	1151.
20	1500	4.35	0.706	20	13.05	2.12	120.4	141.0	5.28	6.10	361.
21	2750	5.55	0.901	15	22.20	3.60	16.6	19.5	0.572	0.659	66.4
22	4000	5.55	0.901	10	33.30	3.60	17.2	20.0	0.586	0.683	103.
23	5000	8.00	1.30	10	48.00	7.79	49.7	58.0	1.18	1.37	298.
24	CYCLE	9.10	1.48	20	27.30	4.43	114.1	134.5	2.40	2.76	342.
25	IDLE	3.60	0.584	20	10.80	1.75	303.3	355.5	16.1	18.6	910.
26	1500	4.50	0.731	20	13.50	2.19	272.9	321.5	11.6	13.4	819.
27	2750	6.00	0.974	15	24.00	3.90	27.0	31.0	0.841	0.992	108.
28	4000	5.60	0.909	10	33.60	5.45	19.8	23.0	0.668	0.779	119.
29	5000	8.00	1.30	10	48.00	7.79	53.4	62.5	1.27	1.47	320.

FUEL TEMP. AT ENGINE ≅ 90 °F DENSITY = 6.16 lb_m/gal (90°F)

FUEL DENSITY AT 72°F = 6.22 lb_m/gal = 0.745 g/ml

COMMENTS ENGINE IDLED AT 900 RPM; TUNED AFTER RUN 17; LOW-SPEED JET SLIGHTLY LEANER AFTER TUNING; FUEL:OIL RATIO 50:1

TEST ENGINE NO. 11 TYPE 1971 CHRYSLER 55 hp

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	lb_m	gal	min	lb_m/hr	gal/hr	g	ml	VOL.	WT.	g / hr
1	IDLE	1.20	0.195	20	3.60	0.586	75.7	90.0	12.2	13.9	227.
2	1500	2.25	0.366	20	6.75	1.10	5.5	6.4	0.462	0.539	16.5
3	2750	3.85	0.627	15	15.40	2.51	0.4	0.5	0.02	0.02	1.6
4	4000	4.00	0.651	10	24.00	3.91	*—	—	—	—	—
5	4600	6.05	0.985	10	36.30	5.91	0.4	0.5	0.01	0.02	2.4
6	IDLE	1.40	0.228	20	4.20	0.684	74.4	87.5	10.1	11.7	223.
7	1500	2.30	0.375	20	6.90	1.12	3.0	3.8	0.268	0.288	9.0
8	2750	3.75	0.611	15	15.00	2.44	0.6	0.6	0.03	0.04	2.4
9	4000	3.90	0.635	10	23.40	3.81	*—	—	—	—	—
10	4600	5.70	0.928	10	34.20	5.57	*—	—	—	—	—
11	CYCLE	5.75	0.936	20	17.25	2.81	2.8	3.6	0.102	0.107	8.4
12	CYCLE	5.90	0.961	20	17.70	2.88	4.9	5.9	0.162	0.183	14.7
13	IDLE	1.35	0.220	20	4.05	0.660	68.7	81.5	9.79	11.2	206.
14	1500	2.15	0.350	20	6.45	1.05	2.9	3.4	0.257	0.297	8.7
15	2750	3.95	0.643	15	15.80	2.57	*—	—	—	—	—
16	4000	4.05	0.660	10	24.30	3.96	*—	—	—	—	—
17	4600	6.20	1.01	10	37.20	6.06	*—	—	—	—	—
18	CYCLE	5.80	0.945	20	17.40	2.83	5.1	5.8	0.162	0.194	15.3

FUEL TEMP. AT ENGINE ≅ 90 °F DENSITY = 6.14 lb_m/gal (90 °F)

FUEL DENSITY AT 72 °F = 6.20 lb_m/gal = 0.743 g/ml

COMMENTS *SAMPLE TOO SMALL TO MEASURE, OBSERVED AS DROPLETS ON INSIDE BOTTLE WALLS; ENGINE IDLED AT 900 RPM; TUNED AFTER RUN 12; NO CARBURETOR ADJUSTMENT; FUEL : OIL RATIO 50:1

TEST ENGINE NO. 12 TYPE 1953 JOHNSON 10 hp

RUN	CONDITION	FUEL USED		TIME, min	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE, g / hr
		lbm	gal		lbm/hr	gal/hr	g	ml	VOL.	WT.	
1	IDLE	2.0	0.32	20	6.0	0.97	97.0	115.5	9.45	10.7	291.
2	1500	2.2	0.36	20	6.6	1.06	72.1	85.0	6.33	7.23	216.
3	2750	2.6	0.42	15	10.4	1.68	43.6	51.5	3.25	3.70	174.
4	4000	2.5	0.40	10	15.0	2.42	5.7	6.4	0.420	0.503	34.2
5	4500	3.2	0.51	10	19.2	3.10	6.2	7.1	0.366	0.427	37.2
6	IDLE	2.2	0.36	20	6.6	1.06	104.3	125.0	9.30	10.5	313.
7	1500	2.4	0.39	20	7.2	1.16	79.6	94.5	6.45	7.31	239.
8	2750	2.3	0.37	15	9.2	1.48	48.3	57.5	4.09	4.63	193.
9	4000	2.6	0.42	10	15.6	2.52	11.1	12.7	0.801	0.941	66.6
10	4500	3.1	0.50	10	18.6	3.00	7.5	8.5	0.449	0.533	45.0
11	CYCLE	3.0	0.48	20	9.0	1.45	39.7	47.5	2.59	2.92	119.
12	CYCLE	2.9	0.47	20	8.7	1.40	34.3	41.0	2.31	2.61	103.

FUEL TEMP. AT ENGINE ≅ 90 °F DENSITY = 6.199 lbm/gal (90°F)

FUEL DENSITY AT 72°F = 6.258 lbm/gal = 0.750 g/ml

COMMENTS ENGINE TESTED AFTER TUNING ONLY; USED PRESSURE-TYPE TANK; ENGINE IDLED AT 1000 RPM; FUEL : OIL RATIO 16 : 1

TEST ENGINE NO. 13 TYPE 1967 JOHNSON 33 hp

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	lb_m	gal	min	lb_m/hr	gal/hr	g	ml	VOL.	WT.	g/hr
1	IDLE	2.30	0.374	20	6.90	1.12	205.0	240.5	17.0	19.6	615.
2	1500	3.00	0.487	20	9.00	1.46	115.6	137.0	7.43	8.50	347.
3	2750	3.05	0.496	15	12.20	1.98	26.5	31.5	1.68	1.92	106.
4	4000	2.90	0.471	10	17.40	2.83	8.6	11.0	0.617	0.654	51.6
5	4500	3.60	0.585	10	21.60	3.51	10.9	13.0	0.587	0.667	65.4
6	IDLE	2.20	0.357	20	6.60	1.07	189.3	226.2	16.7	19.0	568.
7	1500	2.85	0.463	20	8.55	1.39	119.7	141.8	8.09	9.26	359.
8	2750	3.35	0.544	15	13.40	2.18	22.8	27.0	1.31	1.50	91.2
9	4000	2.85	0.463	10	17.10	2.78	12.0	14.0	0.799	0.928	72.0
10	4500	3.50	0.569	10	21.00	3.41	15.9	20.1	0.933	1.00	95.4
11	CYCLE	4.55	0.739	20	13.65	2.22	67.9	80.0	2.86	3.29	204.
12	CYCLE	4.70	0.764	20	14.10	2.29	69.8	82.9	2.87	3.27	209.
13	IDLE	2.05	0.339	20	6.15	0.999	232.5	278.2	21.7	25.0	698.
14	1500	2.85	0.463	20	8.55	1.39	121.3	145.1	8.28	9.38	364.
15	2750	3.10	0.504	15	12.40	2.01	31.7	37.3	1.96	2.25	127.
16	4000	3.15	0.512	10	18.90	3.07	8.8	11.2	0.578	0.616	52.8
17	4800	3.85	0.626	10	23.10	3.75	15.6	19.9	0.840	0.893	93.6
18	CYCLE	4.50	0.731	20	13.50	2.19	63.4	70.1	2.53	3.11	190.

FUEL TEMP. AT ENGINE ≅ 90 °F DENSITY = 6.154 lb_m/gal (90°F)

FUEL DENSITY AT 72°F = 6.212 lb_m/gal = 0.744 g/ml

COMMENTS ENGINE IDLED AT 800 RPM; TUNED AFTER RUN 12; HIGH-SPEED JET SLIGHTLY RICHER AFTER TUNING; FUEL : OIL RATIO 50:1

TEST ENGINE NO. 14 TYPE 1968 MERCURY 95 hp

|←TOP TWO DRAINS→|

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE, g / hr *
RUN	CONDITION	lbm	gal	min	lbm/hr	gal/hr	g	ml	VOL.	WT.	
1	IDLE	1.90	0.308	20	5.70	0.925	18.4	21.0	1.80	2.13	82.8
2	1500	3.05	0.495	20	9.15	1.48	40.9	47.0	2.51	2.96	184.
3	2750	5.70	0.925	15	22.80	3.70	16.1	19.0	0.543	0.623	96.6
4	4000	5.65	0.916	10	33.90	5.50	4.9	5.4	0.156	0.191	44.1
5	5000	9.45	1.53	10	56.70	9.20	2.7	3.2	0.055	0.063	24.3
6	IDLE	1.95	0.316	20	5.85	0.949	15.5	18.5	1.55	1.75	69.8
7	1500	4.00	0.649	20	12.00	1.95	39.1	45.5	1.85	2.15	176.
8	2750	5.75	0.933	15	23.00	3.73	15.3	18.0	0.510	0.587	91.8
9	4000	5.80	0.941	10	34.80	5.64	4.2	5.2	0.146	0.160	37.8
10	5000	9.20	1.49	10	55.20	8.95	2.7	3.4	0.060	0.065	24.3
11	CYCLE	8.55	1.39	20	25.65	4.16	18.3	21.5	0.409	0.472	82.4
12	CYCLE	8.80	1.43	20	26.40	4.28	19.8	23.5	0.434	0.496	89.1
13	IDLE	1.95	0.316	20	5.85	0.949	12.8	15.1	1.26	1.44	57.6
14	1500	4.75	0.770	20	14.25	2.31	35.3	39.9	1.37	1.64	159.
15	2750	5.60	0.908	15	22.40	3.63	17.7	22.8	0.663	0.697	106.
16	4000	5.50	0.892	10	33.00	5.35	6.3	6.8	0.201	0.253	56.7
17	5000	9.40	1.52	10	56.40	9.15	4.9	5.0	0.087	0.115	44.1
18	CYCLE	8.40	1.36	20	25.20	4.09	19.3	21.1	0.410	0.507	86.8
19	† 1500	3.80	0.616	20	11.40	1.85	20.4 18.8	23.5 22.2	2.27	1.96	176.
20	† CYCLE	14.40	2.34	40	21.60	3.50	21.3 17.7	24.9 22.1	0.597	0.531	87.8
21	† IDLE	2.05	0.333	20	6.15	0.998	9.0 8.6	10.5 11.1	1.89	1.72	79.2
22	† CYCLE	16.75	2.72	40	25.12	4.08	24.5 21.0	28.2 27.6	0.599	0.542	102.

FUEL TEMP. AT ENGINE ≅ 90 °F DENSITY = 6.165 lbm/gal (90°F)

FUEL DENSITY AT 72°F = 6.224 lbm/gal = 0.746 g/ml

COMMENTS *RATE SHOWN IS 1.5 TIMES THAT COLLECTED, SINCE 2 OF 3 DRAINS WERE INTERCEPTED; †SEPARATE SAMPLES FROM TOP AND CENTER DRAINS; TUNED AFTER RUN 12; 900 RPM IDLE; NO CARBURETOR CHANGES; FUEL:OIL RATIO 50:1

TEST ENGINE No. 15/15A TYPE 1963 GALE 60 hp / 1968 EVINRUDE 65 hp

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	lbm	gal	min	lbm/hr	gal/hr	g	ml	VOL.	WT.	g/hr
1	IDLE	2.15	0.347	10	12.90	2.08	433.3	531.0	40.4	44.4	2600.
2	1500	2.35	0.380	12	11.75	1.90	439.6	536.0	37.3	41.2	2198.
3	2750	3.75	0.606	10	22.50	3.64	221.6	278.5	12.1	13.0	1330.
4	4000	5.05	0.816	10	30.30	4.90	207.3	260.5	8.43	9.05	1244.
5	5000	7.20	1.16	10	43.20	6.98	254.9	307.2	7.00	7.80	1529.
6	IDLE	2.40	0.388	11.5	12.52	2.02	439.5	539.0	36.7	40.4	2293.
7	1500	2.40	0.388	12	12.00	1.94	443.2	541.5	36.9	40.7	2216.
8	2750	3.60	0.582	10	21.60	3.49	227.7	274.5	12.5	13.9	1366.
9	4000	4.70	0.759	10	28.20	4.56	200.7	240.0	8.35	9.41	1204.
10	5000	7.00	1.13	10	42.00	6.79	247.4	298.5	6.98	7.79	1484.
11	CYCLE	7.80	1.26	20	23.40	3.78	480.7	579.5	12.2	13.6	1442.
12	CYCLE	8.00	1.29	20	24.00	3.88	531.7	643.5	13.2	14.7	1595.
13	IDLE	2.70	0.437	18	9.00	1.46	423.4	514.5	31.1	34.6	1411.
14	1500	3.35	0.542	17.5	11.49	1.86	422.6	514.0	25.1	27.8	1449.
15	2750	4.55	0.737	15	18.20	2.95	19.3	23.5	0.842	0.935	77.2
16	4000	3.70	0.599	10	22.20	3.59	25.7	31.0	1.37	1.53	154.
17	5000	6.25	1.01	10	37.50	6.07	148.6	177.5	4.64	5.24	892.
18	CYCLE	7.15	1.16	20	21.45	3.47	196.9	235.0	5.35	6.07	591.
19	CYCLE	7.15	1.16	20	21.45	3.47	187.0	225.0	5.12	5.77	561.
20	IDLE	2.60	0.421	18	8.67	1.40	420.6	511.5	32.1	35.7	1402.
21	1500	3.75	0.607	19	11.84	1.92	423.9	512.5	22.3	24.9	1339.
22	2750	4.95	0.801	15	19.80	3.21	41.5	50.0	1.65	1.85	166.
23	4000	4.25	0.688	10	25.50	4.13	24.4	29.0	1.11	1.27	146.
24	5000	6.70	1.08	10	40.20	6.51	151.2	180.5	4.42	4.98	907.

No. 15 ⇧

⇩ No. 15A

FUEL TEMP. AT ENGINE ≅ 90 °F DENSITY = 6.189/6.176 lbm/gal (90°F)

FUEL DENSITY AT 72°F = 6.248/6.235 lbm/gal = 0.749/0.747 g/ml

COMMENTS ENGINE REBUILT (NEW POWER HEAD) AFTER RUN 12, HENCE "A" DESIGNATION; IDLED AT 1000 RPM; FUEL:OIL RATIO 24:1 FOR 15 AND 50:1 FOR 15A (AFTER BREAK-IN)

TEST ENGINE NO. 16 TYPE 1964 MERCURY 65 hp

← ONE DRAIN ONLY →

RUN	CONDITION	FUEL USED		TIME, min	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE, g / hr *
		lb$_m$	gal		lb$_m$/hr	gal/hr	g	ml	VOL.	WT.	
1	IDLE	2.50	0.405	20	7.50	1.21	20.4	24.0	1.57	1.80	122.
2	1500	3.75	0.608	20	11.25	1.82	5.0	6.5	0.282	0.294	30.0
3	2750	5.25	0.856	15	21.00	3.43	2.6	4.5	0.139	0.109	20.8
4	4000	4.30	0.691	10	25.80	4.15	1.5	1.8	0.069	0.077	18.0
5	4600	7.50	1.22	10	45.00	7.30	0.8	1.1	0.024	0.024	9.6
6	IDLE	2.80	0.454	20	8.40	1.36	22.8	27.0	1.57	1.80	137.
7	1500	3.95	0.641	20	11.85	1.92	7.6	9.5	0.392	0.424	45.6
8	2750	5.70	0.925	15	22.80	3.70	4.6	6.0	0.171	0.178	36.8
9	4000	4.30	0.691	10	25.80	4.15	0.7	1.0	0.038	0.036	8.4
10	4200	7.35	1.19	10	44.10	7.15	1.6	1.8	0.040	0.048	19.2
11	CYCLE	8.60	1.39	20	25.80	4.18	3.8	5.5	0.105	0.097	22.8
12	CYCLE	8.65	1.40	20	25.95	4.21	6.5	8.5	0.160	0.166	39.0
13	IDLE	2.45	0.397	20	7.35	1.19	24.2	29.0	1.93	2.18	145.
14	1500	3.75	0.608	20	11.25	1.82	6.6	8.5	0.369	0.388	39.6
15	2750	5.50	0.893	15	22.00	3.57	3.5	4.0	0.118	0.140	28.0
16	4000	3.70	0.600	10	22.20	3.60	0.6	0.9	0.040	0.036	7.2
17	5000	7.35	1.19	10	44.10	7.15	1.0	1.3	0.029	0.030	12.0
18	CYCLE	8.35	1.35	20	25.05	4.06	5.0	6.5	0.127	0.132	30.0

FUEL TEMP. AT ENGINE ≅ 90 °F DENSITY = 6.165 lb$_m$/gal (90°F)

FUEL DENSITY AT 72°F = 6.224 lb$_m$/gal = 0.746 g/ml

COMMENTS *SEE ENGINE 4 DATA SHEET; SAMPLES VERY DARK IN COLOR (SEE PHOTO IN TEXT); ENGINE IDLED AT 1000 RPM; NO CARBURETOR ADJUSTMENT; TUNED AFTER RUN 12; FUEL:OIL RATIO 50:1

TEST ENGINE NO. 17 TYPE 1963 MERCURY 85 hp

		FUEL USED		TIME,	FUEL RATE		TOP TWO DRAINS SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	lb_m	gal	min	lb_m/hr	gal/hr	g	ml	VOL.	WT.	g / hr *
1	IDLE	2.40	0.388	20	7.20	1.17	19.9	23.5	1.60	1.83	89.6
2	1500	4.65	0.753	20	13.95	2.26	40.9	46.5	1.63	1.94	184.
3	2750	5.05	0.817	15	20.20	3.27	5.0	5.5	0.178	0.218	30.0
4	4000	4.10	0.664	10	24.60	3.98	†—	—	—	—	—
5	5000	5.80	0.939	10	34.80	5.63	†—	—	—	—	—
6	IDLE	2.50	0.405	20	7.50	1.21	24.2	28.0	1.83	2.13	109.
7	1500	4.40	0.712	20	13.20	2.14	33.6	38.9	1.44	1.68	151.
8	2750	4.65	0.753	15	18.60	3.01	5.7	6.3	0.221	0.270	34.2
9	4000	4.20	0.680	10	25.20	4.08	†—	—	—	—	—
10	5000	5.95	0.963	10	35.70	5.78	†—	—	—	—	—
11	CYCLE	6.90	1.12	20	20.70	3.35	12.6	15.0	0.354	0.403	56.7
12	CYCLE	6.95	1.12	20	20.85	3.37	13.0	15.2	0.359	0.412	58.5
13	IDLE	2.50	0.405	20	7.50	1.21	13.9	16.2	1.06	1.23	62.6
14	1500	4.55	0.736	20	13.65	2.21	35.1	40.9	1.47	1.70	158.
15	2750	5.25	0.850	15	21.00	3.40	9.3	10.4	0.323	0.391	55.8
16	4000	5.60	0.906	10	33.60	5.44	†—	—	—	—	—
17	5000	7.25	1.17	10	43.50	8.01	†—	—	—	—	—
18	CYCLE	7.20	1.17	20	24.60	3.98	11.3	14.8	0.346	0.334	50.8

FUEL TEMP. AT ENGINE ≅ 90 °F DENSITY = 6.178 lb_m/gal (90°F)

FUEL DENSITY AT 72°F = 6.237 lb_m/gal = 0.747 g/ml

COMMENTS *SEE DATA SHEET ON ENGINE 14; †SAMPLE TOO SMALL TO MEASURE; ENGINE IDLED AT 900 RPM; TUNED AFTER RUN 12; NO CARBURETOR ADJUSTMENT; FUEL:OIL RATIO 50:1

TEST ENGINE No. 18 TYPE 1968 EVINRUDE 85 hp

RUN	CONDITION	FUEL USED lbm	FUEL USED gal	TIME, min	FUEL RATE lbm/hr	FUEL RATE gal/hr	SAMPLE (72°F) g	SAMPLE (72°F) ml	SAMPLE % OF FUEL BY VOL.	SAMPLE % OF FUEL BY WT.	SAMPLE RATE, g/hr
1	IDLE	4.50	0.727	20	13.50	2.18	609.9	743.0	27.0	29.9	1830.
2	1500	2.50	0.404	9	16.67	2.69	256.0	314.5	20.6	22.6	1707.
3	2750	5.45	0.881	14	23.36	3.78	258.9	319.5	9.58	10.5	1110.
4	4000	7.10	1.15	10	42.60	6.89	170.8	207.0	4.76	5.30	1025.
5	5000	8.30	1.34	10	49.80	8.05	233.9	282.0	5.56	6.21	1403.
6	IDLE	3.85	0.622	20	11.55	1.87	594.7	723.5	30.7	34.1	1784.
7	1500	2.20	0.356	8.5	15.53	2.51	256.8	320.0	23.7	25.7	1813.
8	2750	5.40	0.873	13	24.92	4.03	253.4	310.5	9.40	10.3	1170.
9	4000	7.35	1.19	10	44.10	7.13	157.6	191.0	4.24	4.73	946.
10	5000	8.35	1.35	10	50.10	8.10	228.6	273.5	5.35	6.04	1372.
11	CYCLE	10.00	1.62	20	30.00	4.85	424.1	513.5	8.37	9.35	1272.
12	CYCLE	10.00	1.62	20	30.00	4.85	417.3	510.5	8.32	9.20	1252.
13	IDLE	4.20	0.679	20	12.60	2.04	226.6	420.5	16.4	11.9	680.
14	1500	4.95	0.800	20	14.85	2.40	240.3	284.0	9.38	10.7	721.
15	2750	5.00	0.808	15	20.00	3.23	78.0	91.0	2.98	3.44	312.
16	4000	6.50	1.05	10	39.00	6.30	86.9	104.4	2.63	2.95	521.
17	5000	8.30	1.34	10	49.80	8.05	218.5	261.5	5.15	5.80	1311.
18	CYCLE	9.55	1.54	20	28.65	4.63	226.3	270.5	4.64	5.22	679.

FUEL TEMP. AT ENGINE ≅ 90 °F DENSITY = 6.186 lbm/gal (90°F)

FUEL DENSITY AT 72°F = 6.245 lbm/gal = 0.748 g/ml

COMMENTS ENGINE IDLED AT 800 RPM; TUNED AFTER RUN 12; FUEL:OIL RATIO 50:1; CARBURETOR SOMEWHAT LEANER AFTER TUNING

TEST ENGINE NO. 19 TYPE 1971 CHRYSLER 45 hp

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE, g/hr
RUN	CONDITION	lb_m	gal	min	lb_m/hr	gal/hr	g	ml	VOL.	WT.	
1	IDLE	1.90	0.308	20	5.70	0.923	2.5	2.5	0.214	0.290	7.5
2	1500	2.50	0.405	20	7.50	1.21	1.0	1.1	0.072	0.088	3.0
3	2750	3.65	0.591	15	14.60	2.36	*——	——	——	——	——
4	4000	3.65	0.591	10	21.90	3.55	*——	——	——	——	——
5	4400	5.05	0.818	10	30.30	4.91	1.4	0.6	0.019	0.061	8.4
6	IDLE	2.10	0.340	20	6.30	1.02	1.5	1.8	0.140	0.157	4.5
7	1200	2.45	0.397	20	7.35	1.19	1.2	1.5	0.100	0.108	3.6
8	2750	4.20	0.680	15	16.80	2.72	*——	——	——	——	——
9	4000	3.85	0.623	10	23.10	3.74	*——	——	——	——	——
10	4500	5.05	0.818	10	30.30	4.91	0.9	0.7	0.023	0.039	4.5
11	CYCLE	5.55	0.899	20	16.66	2.70	1.5	2.0	0.059	0.060	4.5
12	CYCLE	5.85	0.947	20	17.55	2.84	0.9	1.1	0.031	0.034	2.7
13	IDLE	2.10	0.340	20	6.30	1.02	3.1	3.5	0.272	0.325	9.3
14	1200	2.55	0.413	20	7.65	1.24	0.7	0.7	0.045	0.061	2.1
15	1500	2.55	0.413	20	7.65	1.24	*——	——	——	——	——
16	2750	4.20	0.680	15	16.80	2.72	0.6	0.8	0.031	0.031	2.4
17	4000	3.85	0.623	10	23.10	3.74	*——	——	——	——	——
18	4450	5.20	0.842	10	31.20	5.05	0.8	0.8	0.025	0.034	4.8
19	CYCLE	5.95	0.964	20	17.85	2.89	0.9	1.3	0.036	0.033	2.7

FUEL TEMP. AT ENGINE ≅ 90 °F DENSITY = 6.175 lb_m/gal (90°F)

FUEL DENSITY AT 72°F = 6.234 lb_m/gal = 0.747 g/ml

COMMENTS *SAMPLE TOO SMALL TO MEASURE, BUT OBSERVED DROPLETS ON BOTTLE WALLS; ENGINE IDLED AT 750 TO 850 RPM; TUNED AFTER RUN 12; NO CARBURETOR ADJUSTMENT; FUEL:OIL RATIO 50:1

TEST ENGINE NO. 20 TYPE 1968 SEA KING 45 hp

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	lb_m	gal	min	lb_m/hr	gal/hr	g	ml	VOL.	WT.	g / hr
1	IDLE	1.35	0.219	20	4.05	0.656	87.4	106.5	12.8	14.3	262.
2	1500	2.10	0.340	20	6.30	1.02	11.9	14.5	1.13	1.25	35.7
3	2750	2.95	0.478	15	11.80	1.91	1.1	1.3	0.072	0.082	4.4
4	4000	3.10	0.502	10	18.60	3.01	0.4	0.3	0.016	0.028	2.4
5	4750	5.15	0.834	10	30.90	5.00	1.8	2.3	0.073	0.077	10.8
6	IDLE	1.55	0.251	20	4.65	0.753	121.1	148.0	15.6	17.2	363.
7	1200	2.40	0.389	20	7.20	1.17	25.2	30.5	2.07	2.31	75.6
8	2750	3.65	0.591	15	14.60	2.36	0.8	0.6	0.027	0.048	3.2
9	4000	3.30	0.534	10	19.80	3.21	0.1	0.2	0.010	0.007	0.6
10	4750	5.20	0.842	10	31.20	5.05	1.7	2.2	0.069	0.072	10.2
11	CYCLE	5.00	0.810	20	15.00	2.43	13.6	17.0	0.554	0.600	40.8
12	CYCLE	4.95	0.802	20	14.85	2.40	12.9	16.0	0.527	0.574	38.7
13	IDLE	1.50	0.243	20	4.50	0.729	98.0	119.0	12.9	14.4	294.
14	1200	2.00	0.324	20	6.00	0.972	42.0	52.0	4.24	4.63	126.
15	1500	2.00	0.324	20	6.00	0.972	8.8	11.5	0.938	0.970	26.4
16	2750	3.35	0.543	15	13.40	2.17	0.5	0.6	0.029	0.033	2.0
17	4000	3.15	0.510	10	18.90	3.06	0.2	0.3	0.016	0.014	1.2
18	4750	4.30	0.696	10	25.80	4.18	2.2	2.8	0.106	0.113	13.2
19	CYCLE	5.20	0.842	20	15.60	2.53	12.2	15.5	0.486	0.517	36.6

FUEL TEMP. AT ENGINE ≅ 90 °F DENSITY = 6.175 lb_m/gal (90°F)

FUEL DENSITY AT 72°F = 6.234 lb_m/gal = 0.747 g/ml

COMMENTS ENGINE IDLED AT 900 RPM; TUNED AFTER RUN 12;
NO CARBURETOR ADJUSTMENT; FUEL:OIL RATIO 50:1

TEST ENGINE NO. 21 TYPE 1953 JOHNSON 25 hp

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	lb_m	gal	min	lb_m/hr	gal/hr	g	ml	VOL.	WT.	g / hr
1	IDLE	2.25	0.364	20	6.75	1.09	25.7	31.0	2.25	2.52	77.1
2	1500	5.95	0.962	20	17.85	2.89	4.9	5.8	0.159	0.182	14.7
3	2750	5.15	0.833	15	20.60	3.33	3.0	3.6	0.114	0.128	12.0
4	3000	3.55	0.574	10	21.30	3.44	1.2	1.5	0.069	0.075	7.2
5	*3500	2.95	0.477	10	17.70	2.86	2.0	2.6	0.144	0.149	12.0
6	IDLE	2.95	0.477	20	8.85	1.43	3.7	4.2	0.233	0.277	11.1
7	1500	5.50	0.889	20	16.50	2.67	2.0	2.6	0.077	0.080	6.0
8	2750	5.20	0.841	15	20.80	3.36	3.8	4.3	0.135	0.161	15.2
9	3000	4.35	0.703	10	26.10	4.22	2.2	2.8	0.105	0.111	13.2
10	*3700	3.80	0.614	10	22.80	3.69	2.8	2.0	0.086	0.162	16.8
11	CYCLE	5.75	0.930	20	17.25	2.79	4.8	5.7	0.162	0.184	14.4
12	CYCLE	6.90	1.12	20	20.70	3.35	3.5	4.0	0.094	0.112	10.5
13	IDLE	2.95	0.477	20	8.85	1.43	2.0	2.3	0.127	0.149	6.0
14	1500	4.95	0.800	20	14.85	2.40	1.4	1.8	0.059	0.062	4.2
15	2750	4.50	0.728	15	18.00	2.91	1.6	1.9	0.069	0.078	6.4
16	3000	3.95	0.639	10	23.70	3.83	1.5	1.8	0.074	0.084	9.0
17	*3700	4.15	0.671	10	24.90	4.03	1.9	2.2	0.087	0.101	11.4
18	CYCLE	5.75	0.930	20	17.25	2.79	1.3	1.6	0.045	0.050	3.9

FUEL TEMP. AT ENGINE ≅ 90 °F DENSITY = 6.184 lb_m/gal (90°F)

FUEL DENSITY AT 72°F = 6.243 lb_m/gal = 0.748 g/ml

COMMENTS USED PRESSURE-TYPE FUEL TANK; ENGINE IDLED AT 850 RPM; FUEL:OIL RATIO 24:1; TUNED AFTER RUN 12; NO CARBURETOR ADJUSTMENT; BOAT AND LOAD SOMEWHAT OVERSIZE FOR ENGINE *TOP RPM

TEST ENGINE No. 22 TYPE 1960 JOHNSON 75 hp

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	lbm	gal	min	lbm/hr	gal/hr	g	ml	VOL.	WT.	g / hr
1	IDLE	2.45	0.396	16.5	8.91	1.44	446.7	543.0	36.2	40.2	1620
2	1500	3.10	0.501	17	10.94	1.77	451.3	539.5	28.4	32.1	1590
3	2750	6.05	0.977	13.5	26.88	4.34	255.0	306.5	8.29	9.29	1130
4	3800	5.60	0.904	10	33.60	5.43	139.6	167.0	4.88	5.50	838
5	4200	7.25	1.17	10	43.50	7.02	154.6	186.0	4.20	4.70	928
6	IDLE	2.25	0.363	20	6.75	1.09	283.0	336.5	24.4	27.7	849
7	1500	3.20	0.517	20	9.60	1.55	335.1	397.5	20.3	23.1	1010
8	2750	6.25	1.01	14.6	25.71	4.15	257.5	——	——	9.08	1060
9	3800	4.80	0.775	10	28.80	4.65	148.0	176.0	6.00	6.80	888
10	4200	7.25	1.17	10	43.50	7.02	147.5	177.5	4.04	4.49	885
11	CYCLE	7.45	1.20	20	22.35	3.61	308.3	369.0	8.12	9.12	925
12	CYCLE	7.25	1.17	20	21.75	3.51	311.3	366.5	8.28	9.47	934
13	IDLE	2.95	0.476	20	8.85	1.43	376.7	450.5	25.0	28.2	1130
14	1500	4.10	0.662	20	12.30	1.99	456.8	542.5	21.6	24.6	1370
15	2750	6.85	1.11	15	27.40	4.42	255.2	304.5	7.25	8.21	1020
16	3800	5.65	0.912	10	33.90	5.47	153.3	183.0	5.30	5.98	920
17	5000	7.25	1.17	10	43.50	7.02	80.0	95.5	2.16	2.43	480
18	CYCLE	8.35	1.35	20	25.05	4.04	409.6	498.0	9.75	10.8	1230

FUEL TEMP. AT ENGINE ≅ 90 °F DENSITY = 6.193 lbm/gal (90°F)

FUEL DENSITY AT 72°F = 6.252 lbm/gal = 0.749 g/ml

COMMENTS ENGINE IDLED AT 900 TO 1000 RPM; FUEL:OIL RATIO 24:1; TUNED AFTER RUN 12, INCLUDING CARBURETOR ADJUSTMENT; ENGINE RAN ROUGHLY AT 4000 RPM, SO HIGH MID-SPEED USED WAS 3800 RPM

TEST ENGINE NO. 23 TYPE 1970 CHRYSLER 5 hp

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	lb_m	gal	min	lb_m/hr	gal/hr	g	ml	VOL.	WT.	g / hr
1	IDLE	0.50	0.080	20	1.50	0.240	24.4	30.0	9.9	11.	73.2
2	1500	0.50	0.080	20	1.50	0.240	0.9	1.2	0.40	0.40	2.7
3	2750	0.85	0.136	15	3.40	0.543	17.2	21.0	4.1	4.5	68.8
4	4000	0.90	0.144	10	5.40	0.862	45.6	53.5	9.8	11.	274.
5	*4400	0.90	0.144	10	5.40	0.862	42.2	50.0	9.2	10.	253.
6	IDLE	0.65	0.104	20	1.95	0.311	24.9	30.0	7.6	8.4	74.7
7	1500	0.60	0.096	20	1.80	0.287	0.6	0.9	0.25	0.22	1.8
8	2750	0.80	0.128	15	3.20	0.511	16.0	19.0	3.9	4.4	64.0
9	4000	0.85	0.136	10	5.10	0.814	43.2	50.0	9.7	11.	259.
10	*4400	0.90	0.144	10	5.40	0.862	34.7	41.0	7.5	8.5	208.
11	CYCLE	1.10	0.176	20	3.30	0.527	44.6	52.0	7.81	8.94	134.
12	CYCLE	1.25	0.200	20	3.75	0.599	38.3	41.0	5.42	6.45	115.

FUEL TEMP. AT ENGINE ≅ 80 °F DENSITY = 6.263 lb_m/gal (80°F)

FUEL DENSITY AT 72°F = 6.290 lb_m/gal = 0.754 g/ml

COMMENTS *TOP RPM; TESTED AFTER TUNING ONLY; ENGINE IDLED AT 900 RPM; FUEL : OIL RATIO 16:1

TEST ENGINE NO. 24 TYPE *1972 EVINRUDE 9.5 hp

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	lb_m	gal	min	lb_m/hr	gal/hr	g	ml	VOL.	WT.	g / hr
1	IDLE	0.55	0.089	20	1.65	0.267	46.9	55.5	16.5	18.8	141.
2	1500	1.10	0.178	20	3.30	0.534	51.0	61.0	9.05	10.2	153.
3	2750	1.25	0.202	15	5.00	0.810	27.0	31.5	4.12	4.76	108.
4	4000	1.20	0.194	10	7.20	1.17	7.1	9.0	1.23	1.30	42.6
5	† 4600	1.30	0.210	10	7.80	1.26	5.7	8.0	1.01	0.967	34.2
6	IDLE	0.85	0.138	20	2.55	0.413	49.5	58.5	11.2	12.8	148.
7	1500	0.90	0.146	20	2.70	0.437	48.2	57.5	10.4	11.8	145.
8	2750	1.50	0.243	15	6.00	0.972	23.9	29.0	3.15	3.51	95.6
9	4000	1.50	0.243	10	9.00	1.46	5.7	8.0	0.870	0.838	34.2
10	† 4600	1.65	0.267	10	9.90	1.60	5.7	7.0	0.693	0.762	34.3
11	CYCLE	1.95	0.316	20	5.85	0.947	29.1	35.0	2.93	3.29	87.3
12	CYCLE	1.95	0.316	20	5.85	0.947	29.5	35.0	2.93	3.34	88.5
13	IDLE	0.65	0.105	20	1.95	0.316	52.0	61.0	15.3	17.6	156.
14	1500	1.00	0.162	20	3.00	0.486	54.8	65.0	10.6	12.1	164.
15	2750	1.65	0.267	15	6.60	1.07	23.5	28.0	2.77	3.14	94.0
16	4000	1.50	0.243	10	9.00	1.46	7.0	9.0	0.978	1.03	42.0
17	† 4600	1.55	0.251	10	9.30	1.51	6.7	8.5	0.895	0.953	40.2
18	CYCLE	2.10	0.340	20	6.30	1.02	31.1	37.0	2.87	3.26	93.3

FUEL TEMP. AT ENGINE ≅ 90 °F DENSITY = 6.18 lb_m/gal (90°F)

FUEL DENSITY AT 72°F = 6.24 lb_m/gal = 0.747 g/ml

COMMENTS *ORIGINALLY DRAINLESS ENGINE CONVERTED TO DRAINED CONFIGURATION FOR TESTS; †TOP RPM; IDLED AT 1000 RPM; NO CARBURETOR ADJUSTMENT; FUEL:OIL RATIO 50:1; TUNED AFTER RUN 12

TEST ENGINE NO. 25 TYPE 1971 JOHNSON 9.5 hp

|← NOTE QUALIFICATIONS BELOW →|

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	lb_m	gal	min	lb_m/hr	gal/hr	g	ml	VOL.	WT.	g / hr
1	IDLE	1.25	0.200	20	3.75	0.600	6.1	6.4	0.845	1.08	18.3
2	1500	1.55	0.248	20	4.65	0.744	3.2	3.2	0.341	0.455	9.6
3	2750	1.85	0.296	15	7.40	1.18	1.7	1.8	0.161	0.203	6.8
4	* 3900	1.55	0.248	10	9.30	1.49	7.5	8.3	0.884	1.07	45.0
5	IDLE	1.10	0.176	20	3.30	0.528	2.4	3.3	0.495	0.481	7.2
6	1500	1.30	0.208	20	3.90	0.624	2.2	2.4	0.305	0.373	6.6
7	2750	1.80	0.288	15	7.20	1.15	2.8	3.2	0.294	0.343	11.2
8	* 3900	1.75	0.280	10	10.50	1.68	7.2	8.1	0.764	0.907	43.2
9	CYCLE	2.15	0.344	20	6.45	1.03	8.1	8.8	0.676	0.831	24.3
10	CYCLE	2.35	0.376	20	7.05	1.13	8.9	10.3	0.724	0.835	26.7

FUEL TEMP. AT ENGINE ≅ 70 °F DENSITY = 6.25 lb_m/gal (70°F)

FUEL DENSITY AT 72°F = 6.25 lb_m/gal = 0.748 g/ml

COMMENTS * TOP RPM; TESTED ONLY AFTER TUNING; SAMPLES HAD AN EMULSIFIED LAYER (WHITE) UNDER "SAMPLE" SHOWN ABOVE (SEE TEXT); IDLED AT 900 RPM; FUEL : OIL RATIO 50:1

TEST ENGINE NO. 26 TYPE 1970 JOHNSON 6 hp

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	$\mathrm{lb_m}$	gal	min	$\mathrm{lb_m/hr}$	gal/hr	g	ml	VOL.	WT.	g / hr
1	IDLE	0.55	0.087	20	1.65	0.261	8.0	9.0	2.73	3.21	24.0
2	1500	0.60	0.095	20	1.80	0.285	11.0	12.6	3.51	4.04	33.0
3	2750	0.80	0.127	15	3.20	0.506	0.6	0.9	0.187	0.165	2.4
4	*3800	0.70	0.111	10	4.20	0.665	†——	——	——	——	——
5	IDLE	0.30	0.048	20	0.90	0.142	4.4	4.9	2.73	3.23	13.2
6	1500	0.70	0.111	20	2.10	0.332	13.6	16.0	3.81	4.28	40.8
7	2750	0.75	0.119	15	3.00	0.457	5.3	6.2	1.38	1.56	21.2
8	*3800	0.95	0.150	10	5.70	0.902	0.9	1.0	0.176	2.09	5.4
9	CYCLE	1.00	0.158	20	3.00	0.475	1.7	2.4	0.401	0.375	5.1
10	CYCLE	1.25	0.198	20	3.75	0.593	6.1	7.0	0.934	1.08	18.3
11	IDLE	0.55	0.087	20	1.65	0.261	5.4	5.8	1.76	2.16	16.2
12	1500	0.65	0.103	20	1.95	0.308	12.5	14.7	3.77	4.24	37.5
13	2750	0.85	0.134	15	3.40	0.538	1.2	1.1	0.217	0.311	4.8
14	*3900	0.85	0.134	10	5.10	0.807	0.9	0.9	0.177	0.233	5.4
15	CYCLE	1.15	0.182	20	3.45	0.546	2.9	3.4	0.494	0.556	8.7

FUEL TEMP. AT ENGINE ≅ 50 °F DENSITY = 6.32 $\mathrm{lb_m/gal}$ (50°F)

FUEL DENSITY AT 72°F = 6.25 $\mathrm{lb_m/gal}$ = 0.748 g/ml

COMMENTS *TOP RPM ; † TOO SMALL TO MEASURE ; ENGINE IDLED AT 1100 RPM; NO CARBURETOR ADJUSTMENT ; FUEL:OIL RATIO 50:1 ; \TUNED AFTER RUN 10

TEST ENGINE NO. 27 TYPE *1972 JOHNSON 9.5 hp

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	lb_m	gal	min	lb_m/hr	gal/hr	g	ml	VOL.	WT.	g / hr
1	IDLE	1.50	0.238	20	4.50	0.715	206.6	254.5	28.2	30.4	620.
2	1500	1.65	0.262	20	4.95	0.787	215.9	266.5	26.9	28.8	648.
3	2750	1.65	0.262	15	6.60	1.05	38.2	46.5	4.69	5.10	153.
4	†4000	1.50	0.238	10	9.00	1.43	8.6	10.3	1.14	1.26	51.6
5	IDLE	1.45	0.231	20	4.35	0.692	213.9	261.0	29.8	32.5	642.
6	1500	1.85	0.294	20	5.55	0.882	180.9	224.0	20.1	21.6	543.
7	2750	1.60	0.254	15	6.40	1.02	37.2	46.0	4.78	5.13	149.
8	†4000	1.55	0.246	10	9.30	1.48	7.5	9.5	1.02	1.07	45.0
9	CYCLE	2.25	0.358	20	6.75	1.07	74.9	92.0	6.79	7.34	225.
10	CYCLE	2.30	0.366	20	6.90	1.10	75.0	92.0	6.64	7.19	225.
11	IDLE	1.25	0.199	20	3.75	0.596	205.5	254.0	33.7	36.2	616.
12	1500	1.75	0.278	20	5.25	0.835	173.2	214.0	20.3	21.8	520.
13	2750	1.70	0.270	15	6.80	1.08	32.4	39.5	3.86	4.20	130.
14	†4000	1.55	0.246	10	9.30	1.48	6.4	8.5	0.913	0.910	38.4
15	CYCLE	2.20	0.350	20	6.60	1.05	62.8	77.5	5.85	6.29	188.

FUEL TEMP. AT ENGINE ≅ 60 °F DENSITY = 6.29 lb_m/gal (60°F)

FUEL DENSITY AT 72°F = 6.25 lb_m/gal = 0.748 g/ml

COMMENTS *ORIGINALLY DRAINLESS ENGINE CONVERTED TO DRAINED CONFIGURATION FOR TESTS; †TOP RPM; IDLED AT 1000 RPM; NO CARBURETOR ADJUSTMENT; FUEL:OIL RATIO 50:1; TUNED AFTER RUN 10

TEST ENGINE NO. 28 TYPE 1971 EVINRUDE 9.5 hp

RUN	CONDITION	FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE, g/hr
		lb_m	gal	min	lb_m/hr	gal/hr	g	ml	VOL.	WT.	
1	IDLE	1.10	0.175	20	3.30	0.525	172.1	209.0	31.6	34.5	516.
2	1500	1.55	0.246	20	4.65	0.739	195.9	237.0	25.5	27.9	588.
3	2750	1.55	0.246	15	6.20	0.986	41.7	50.0	5.37	5.93	167.
4	4000	1.55	0.246	10	9.30	1.48	6.1	7.5	0.805	0.868	36.6
5	*4500	1.65	0.262	10	9.90	1.57	13.0	16.5	1.66	1.74	78.0
6	IDLE	0.95	0.151	20	2.85	0.453	170.4	207.0	36.2	39.5	511.
7	1500	1.30	0.207	20	3.90	0.620	187.4	230.0	29.4	31.8	562.
8	2750	1.60	0.254	15	6.40	1.02	52.9	64.0	6.66	7.29	212.
9	4000	1.75	0.278	10	10.50	1.67	8.5	11.0	1.05	1.07	51.0
10	*4500	1.75	0.278	10	10.50	1.67	14.4	17.5	1.66	1.81	86.4
11	CYCLE	2.15	0.342	20	6.45	1.03	75.2	90.5	6.99	7.71	226.
12	CYCLE	2.45	0.390	20	7.35	1.17	81.2	97.5	6.60	7.31	244.
13	IDLE	1.05	0.167	20	3.15	0.501	178.1	216.5	34.2	37.4	534.
14	1500	1.55	0.246	20	4.65	0.739	203.4	240.5	25.8	28.9	610.
15	2750	1.50	0.238	15	6.00	0.954	44.7	52.5	5.83	6.57	179.
16	4000	1.45	0.231	10	8.70	1.38	11.7	15.0	1.72	1.78	70.2
17	*4500	1.60	0.254	10	9.60	1.53	11.9	15.0	1.56	1.64	71.4
18	CYCLE	2.05	0.326	20	6.15	0.978	84.5	102.7	8.32	9.09	254.

FUEL TEMP. AT ENGINE ≅ 60 °F DENSITY = 6.29 lb_m/gal (60°F)

FUEL DENSITY AT 72°F = 6.25 lb_m/gal = 0.748 g/ml

COMMENTS * TOP RPM; IDLED AT 1000 RPM; NO CARBURETOR ADJUSTMENT; FUEL:OIL RATIO 50:1; TUNED AFTER RUN 12

TEST ENGINE NO. 29 TYPE 1967 MERCURY 6 hp

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	lb_m	gal	min	lb_m/hr	gal/hr	g	ml	VOL.	WT.	g/hr
1	IDLE	0.45	0.072	20	1.35	0.215	19.8	24.0	8.81	9.70	59.4
2	1500	0.70	0.111	20	2.10	0.334	16.0	19.5	4.64	5.04	48.0
3	2750	0.60	0.095	15	2.40	0.382	39.5	47.0	13.1	14.5	158.
4	4000	0.40	0.064	10	2.40	0.382	25.9	31.0	12.8	14.3	155.
5	5400	0.65	0.103	10	3.90	0.620	2.4	3.6	0.923	0.814	14.4
6	IDLE	0.35	0.056	20	1.05	0.167	13.0	16.0	7.55	8.19	39.0
7	1500	0.55	0.087	20	1.65	0.262	9.0	11.5	3.49	3.61	27.0
8	2750	0.50	0.079	15	2.00	0.238	26.5	32.0	10.7	11.7	106.
9	4000	0.50	0.079	10	3.00	0.238	22.1	27.0	9.03	9.74	133.
10	5400	0.65	0.103	10	3.90	0.620	2.7	3.8	0.975	0.916	16.2
11	CYCLE	0.80	0.127	20	2.40	0.382	23.0	27.0	5.62	6.34	69.0
12	CYCLE	0.80	0.127	20	2.40	0.382	25.8	30.5	6.34	7.11	77.4
13	IDLE	0.45	0.072	20	1.35	0.215	11.4	15.0	5.50	5.58	34.2
14	1500	0.55	0.087	20	1.65	0.262	10.5	13.0	3.95	4.21	31.5
15	2750	0.55	0.087	15	2.20	0.350	31.2	37.5	11.4	12.5	125.
16	4000	0.45	0.072	10	2.70	0.429	14.6	18.0	6.60	7.15	87.6
17	5400	0.70	0.111	10	4.20	0.668	3.4	3.9	0.928	1.07	20.4
18	CYCLE	0.85	0.135	20	2.55	0.405	20.8	25.0	4.89	5.39	62.4

FUEL TEMP. AT ENGINE ≅ 60 °F DENSITY = 6.29 lb_m/gal (60°F)

FUEL DENSITY AT 72°F = 6.25 lb_m/gal = 0.748 g/ml

COMMENTS SAMPLES HAD AN EMULSIFIED LAYER (WHITE) UNDER FUEL-BASED MATERIAL (SEE TEXT); ENGINE IDLED AT 1000 RPM; ENGINE WAS TESTED AFTER TUNING ONLY; FUEL : OIL RATIO 50:1

TEST ENGINE No. 30 TYPE 1971 MERCURY 9.8 hp

RUN	CONDITION	FUEL USED		TIME, min	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE, g/hr
		lb_m	gal		lb_m/hr	gal/hr	g	ml	VOL.	WT.	
1	IDLE	0.36	0.059	20	1.08	0.178	22.6	29.0	13.0	13.8	67.8
2	1500	0.53	0.087	20	1.59	0.262	21.1	26.0	7.89	8.78	63.3
3	2600	1.02	0.168	15	4.08	0.671	19.7	25.0	3.93	4.26	78.8
4	4000	0.79	0.130	10	4.74	0.780	1.6	2.0	0.41	0.45	9.6
5	*4600	1.19	0.196	10	7.14	1.17	1.8	2.3	0.31	0.33	10.8
6	IDLE	0.36	0.059	20	1.08	0.178	19.8	25.0	11.2	12.1	59.4
7	1500	0.55	0.090	20	1.65	0.271	22.2	27.0	7.93	8.90	66.6
8	2750	0.82	0.135	15	3.28	0.539	16.2	22.0	4.31	4.36	64.8
9	4000	0.84	0.138	10	5.04	0.829	2.0	2.3	0.44	0.52	12.0
10	*4600	1.15	0.189	10	6.90	1.13	2.4	2.4	0.34	0.46	14.4
11	CYCLE	1.26	0.207	20	3.78	0.622	7.4	9.0	1.15	1.29	22.2
12	CYCLE	1.35	0.222	20	4.05	0.666	9.3	11.5	1.37	1.52	27.9
13	IDLE	0.37	0.061	20	1.11	0.183	21.1	26.5	11.5	12.6	63.3
14	1500	0.54	0.089	20	1.62	0.266	21.9	27.0	8.01	8.94	65.7
15	2750	0.80	0.132	15	3.20	0.526	15.4	20.0	4.00	4.24	61.6
16	4000	0.84	0.138	10	5.04	0.829	1.8	2.2	0.42	0.47	10.8
17	*4500	1.21	0.199	10	7.26	1.19	1.3	2.1	0.28	0.24	7.8
18	CYCLE	1.20	0.197	20	3.60	0.592	10.2	12.0	1.61	1.87	30.6

FUEL TEMP. AT ENGINE ≅ 70 °F DENSITY = 6.08 lb_m/gal (70°F)

FUEL DENSITY AT 72°F = 6.08 lb_m/gal = 0.728 g/ml

COMMENTS *TOP RPM; CHANGED PLUGS AFTER RUN 12; ENGINE IDLED AT 700 RPM; NO CARBURETOR ADJUSTMENT; FUEL:OIL RATIO 50:1

TEST ENGINE NO. 31 TYPE 1972 EVINRUDE 18 hp

RUN	CONDITION	FUEL USED		TIME,	FUEL RATE		SAMPLE(72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE, g / hr
		lbm	gal	min	lbm/hr	gal/hr	g	ml	VOL.	WT.	
1	IDLE	1.29	0.212	20	3.87	0.635	41.9	53.0	6.60	7.16	126.
2	1500	1.51	0.248	20	4.53	0.744	18.3	24.0	2.56	2.67	54.9
3	2750	2.02	0.332	15	8.08	1.33	10.0	12.0	0.955	1.09	40.0
4	4000	1.97	0.323	10	11.82	1.94	6.6	8.0	0.654	0.739	39.6
5	5000	2.56	0.420	10	15.36	2.52	7.0	8.5	0.535	0.603	42.0
6	IDLE	1.35	0.222	20	4.05	0.665	43.1	55.0	6.54	7.04	129.
7	1500	1.53	0.251	20	4.59	0.754	19.8	26.0	2.74	2.85	59.4
8	2750	2.00	0.328	15	8.00	1.31	10.6	13.0	1.05	1.17	42.4
9	4000	2.02	0.332	10	12.12	1.99	5.5	7.0	0.557	0.600	33.0
10	5000	2.52	0.414	10	15.12	2.48	6.1	7.5	0.479	0.534	36.6
11	CYCLE	2.94	0.483	20	8.82	1.45	16.8	20.5	1.12	1.26	50.4
12	CYCLE	2.94	0.483	20	8.82	1.45	15.0	18.5	1.01	1.12	45.0
13	IDLE	1.31	0.215	20	3.93	0.645	42.6	52.5	6.45	7.17	128.
14	1500	1.83	0.300	20	5.49	0.901	18.1	23.0	2.03	2.18	54.3
15	2750	2.06	0.338	15	8.24	1.35	9.2	11.5	0.899	0.985	36.8
16	4000	1.99	0.327	10	11.94	1.96	5.8	7.5	0.606	0.643	34.8
17	5000	2.45	0.402	10	14.70	2.41	3.8	6.0	0.394	0.342	22.8
18	CYCLE	3.09	0.507	20	9.27	1.52	14.0	17.5	0.912	0.999	42.0

FUEL TEMP. AT ENGINE ≅ 70 °F DENSITY = 6.09 lbm/gal (70°F)

FUEL DENSITY AT 72°F = 6.08 lbm/gal = 0.729 g/ml

COMMENTS PLUGS CHANGED AFTER RUN 3 DUE TO POOR ENGINE OPERATION; LOW-SPEED JET LEANED SLIGHTLY AFTER RUN 12; ENGINE IDLED AT 1000 RPM; FUEL:OIL RATIO 50:1

TEST ENGINE NO. 32 TYPE 1971 CHRYSLER 35 hp

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	lb_m	gal	min	lb_m/hr	gal/hr	g	ml	VOL.	WT.	g / hr
1	IDLE	1.73	0.284	20	5.19	0.852	8.3	10.0	0.930	1.06	24.9
2	1500	2.58	0.424	20	7.74	1.27	3.4	4.1	0.255	0.316	10.2
3	2750	3.19	0.524	15	12.76	2.10	0.8	0.8	0.040	0.055	3.2
4	4000	3.12	0.512	10	18.72	3.07	0.1	*	—	0.007	0.6
5	4750	3.94	0.647	10	23.64	3.88	0.5	0.4	0.016	0.028	3.0
6	IDLE	1.63	0.268	20	4.89	0.803	5.9	7.2	0.710	0.798	17.7
7	1500	2.61	0.429	20	7.83	1.29	1.4	1.4	0.086	0.118	4.2
8	2750	3.35	0.550	15	13.40	2.20	2.1	2.6	0.125	0.138	8.4
9	4000	3.02	0.496	10	18.12	2.98	1.7	1.8	0.096	0.124	10.2
10	4750	3.77	0.619	10	22.62	3.71	0.7	0.7	0.030	0.041	4.2
11	CYCLE	4.65	0.764	20	13.95	2.29	2.7	3.3	0.114	0.128	8.1
12	CYCLE	4.60	0.755	20	13.80	2.27	2.7	3.1	0.108	0.129	8.1
13	IDLE	1.60	0.263	20	4.80	0.788	3.6	4.2	0.422	0.496	10.8
14	1500	2.60	0.427	20	7.80	1.28	3.5	4.2	0.260	0.297	10.5
15	2750	3.29	0.540	15	13.16	2.16	0.9	0.8	0.039	0.060	3.6
16	4000	3.20	0.525	10	19.20	3.15	0.5	0.4	0.020	0.034	3.0
17	4750	4.27	0.701	10	25.62	4.21	0.3	0.3	0.011	0.015	1.8
18	CYCLE	4.76	0.782	20	14.28	2.34	1.0	1.1	0.037	0.046	3.0

FUEL TEMP. AT ENGINE ≅ 70 °F DENSITY = 6.09 lb_m/gal (70 °F)

FUEL DENSITY AT 72°F = 6.09 lb_m/gal = 0.729 g/ml

COMMENTS ENGINE TUNED BEFORE RUN 1 DUE TO POOR PERFORMANCE; ENGINE IDLED AT 1000 RPM; FUEL:OIL RATIO 50:1

TEST ENGINE NO. 33 TYPE 1966 JOHNSON 40 hp

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	lb_m	gal	min	lb_m/hr	gal/hr	g	ml	VOL.	WT.	g / hr
1	IDLE	1.32	0.217	20	3.96	0.652	8.0	9.5	1.16	1.34	24.0
2	1500	1.82	0.300	20	5.46	0.900	3.8	4.5	0.396	0.460	11.4
3	2750	1.94	0.320	15	7.76	1.28	3.5	3.8	0.289	0.398	14.0
4	4000	2.62	0.432	10	15.72	2.59	3.0	3.8	0.183	0.252	18.0
5	4500	3.84	0.633	10	23.04	3.80	6.6	7.4	0.275	0.379	39.6
6	IDLE	1.40	0.231	20	4.20	0.692	50.4	59.8	6.75	7.94	151.2
7	1500	1.76	0.290	20	5.28	0.870	29.6	35.0	3.19	3.71	88.8
8	2750	2.19	0.361	15	8.76	1.44	6.3	7.2	0.527	0.634	25.2
9	4000	2.70	0.445	10	16.20	2.67	2.8	3.3	0.196	0.229	16.8
10	4500	3.78	0.623	10	22.68	3.74	5.0	5.7	0.242	0.292	30.0
11	CYCLE	3.72	0.613	20	11.16	1.84	12.7	15.0	0.646	0.753	38.1
12	CYCLE	3.91	0.644	20	11.73	1.93	11.8	15.0	0.615	0.665	35.4

FUEL TEMP. AT ENGINE ≅ 80 °F DENSITY = 6.07 lb_m/gal (80°F)

FUEL DENSITY AT 72°F = 6.09 lb_m/gal = 0.730 g/ml

COMMENTS ENGINE IDLED AT 1000 RPM; FUEL : OIL RATIO 50:1 ; RUN IN TUNED CONDITION ONLY

TEST ENGINE NO. 34 TYPE 1971 EVINRUDE 9.5 hp

RUN	CONDITION	FUEL USED		TIME, min	FUEL RATE		SAMPLE(72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE, g / hr
		lb$_m$	gal		lb$_m$/hr	gal/hr	g	ml	VOL.	WT.	
1	IDLE	0.86	0.141	20	2.58	0.423	135.3	186.	34.8	34.7	406.
2	1500	1.23	0.202	20	3.69	0.605	146.7	172.	22.5	26.3	440.
3	2750	1.66	0.272	15	6.64	1.09	81.0	100.	9.71	10.8	324.
4	4000	1.54	0.252	10	9.24	1.51	8.9	14.0	1.47	1.27	53.4
5	*4250	1.66	0.272	10	9.96	1.63	10.5	15.0	1.46	1.39	63.0
6	IDLE	0.89	0.146	20	2.67	0.438	132.9	168.	30.4	32.9	399.
7	1500	1.28	0.210	20	3.84	0.630	157.8	200.	25.2	27.2	473.
8	2750	1.68	0.275	15	6.72	1.10	64.4	80.8	7.76	8.45	258.
9	4000	1.56	0.256	10	9.36	1.53	8.9	14.0	1.44	1.26	53.4
10	*4250	1.65	0.270	10	9.90	1.62	10.0	15.0	1.47	1.34	60.0
11	CYCLE	2.30	0.377	20	6.90	1.13	80.8	100.	7.01	7.74	242.
12	CYCLE	2.37	0.389	20	7.11	1.17	77.9	98.0	6.66	7.25	234.
13	IDLE	0.97	0.159	20	2.91	0.477	130.1	165.	27.4	29.6	390.
14	1500	1.25	0.205	20	3.75	0.615	150.1	188.	24.2	26.5	450.
15	2750	1.81	0.297	15	7.24	1.19	68.0	84.0	7.47	8.28	272.
16	4000	1.66	0.272	10	9.96	1.63	12.3	18.0	1.75	1.63	73.8
17	*4250	1.63	0.267	10	9.78	1.60	10.2	15.0	1.48	1.38	61.2
18	CYCLE	2.34	0.384	20	7.02	1.15	71.3	89.0	6.12	6.72	214.

FUEL TEMP. AT ENGINE ≅ 70 °F DENSITY = 6.10 lb$_m$/gal (70°F)

FUEL DENSITY AT 72°F = 6.10 lb$_m$/gal = 0.731 g/ml

COMMENTS TUNED AFTER RUN 12; *MAXIMUM RPM; IDLED AT 900 RPM; FUEL:OIL RATIO 50:1; NO CARBURETOR ADJUSTMENT

TEST ENGINE No. 35 TYPE 1964 EVINRUDE 9.5 hp

		FUEL USED		TIME,	FUEL RATE		SAMPLE (72°F)		SAMPLE % OF FUEL BY		SAMPLE RATE,
RUN	CONDITION	lb$_m$	gal	min	lb$_m$/hr	gal/hr	g	ml	VOL.	WT.	g/hr
1	IDLE	0.84	0.138	20	2.52	0.413	34.1	42.0	8.04	8.95	102.
2	1500	1.20	0.197	20	3.60	0.590	79.8	97.0	13.0	14.7	239.
3	2750	1.65	0.270	15	6.60	1.08	55.0	67.0	6.56	7.35	220.
4	4000	1.63	0.267	10	9.78	1.60	7.0	9.0	0.890	0.947	42.0
5	*4350	1.67	0.274	10	10.02	1.64	6.7	9.0	0.868	0.884	40.2
6	IDLE	0.90	0.148	20	2.70	0.443	74.2	90.0	16.1	18.2	223.
7	1500	1.19	0.195	20	3.57	0.585	90.4	111.	15.0	16.7	271.
8	2750	1.73	0.284	15	6.92	1.13	43.5	53.0	4.93	5.54	174.
9	4000	1.57	0.257	10	9.42	1.54	6.8	8.5	0.874	0.955	40.8
10	*4350	1.63	0.267	10	9.78	1.60	7.9	10.0	0.989	1.07	47.4
11	CYCLE	2.32	0.380	20	6.96	1.14	47.1	58.0	4.03	4.48	141.
12	CYCLE	2.29	0.375	20	6.87	1.13	50.4	62.0	4.37	4.85	151.
13	IDLE	0.84	0.138	20	2.52	0.413	58.1	71.0	13.6	15.2	174.
14	1500	1.18	0.193	20	3.54	0.580	87.2	106.	14.6	16.3	262.
15	2750	1.62	0.266	15	6.48	1.06	45.4	56.0	5.56	6.18	182.
16	4000	1.57	0.257	10	9.42	1.54	6.6	8.5	0.874	0.927	39.6
17	*4350	1.59	0.261	10	9.54	1.56	8.7	11.0	1.11	1.21	52.2
18	CYCLE	2.30	0.377	20	6.90	1.13	45.3	55.5	3.89	4.34	136.

FUEL TEMP. AT ENGINE ≅ 70 °F DENSITY = 6.10 lb$_m$/gal (70°F)

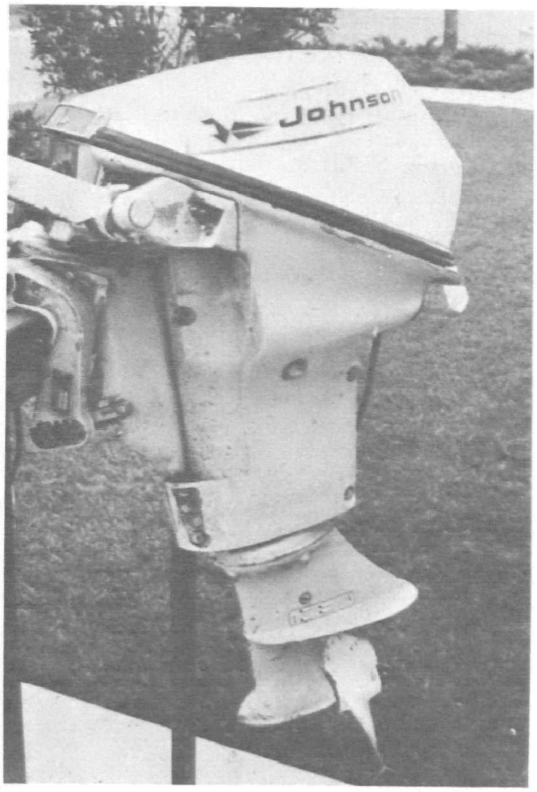
FUEL DENSITY AT 72°F = 6.09 lb$_m$/gal = 0.730 g/ml

COMMENTS *TOP RPM ; ENGINE IDLED AT 900 RPM ; TUNED AFTER RUN 12 ; FUEL : OIL RATIO 50 : 1

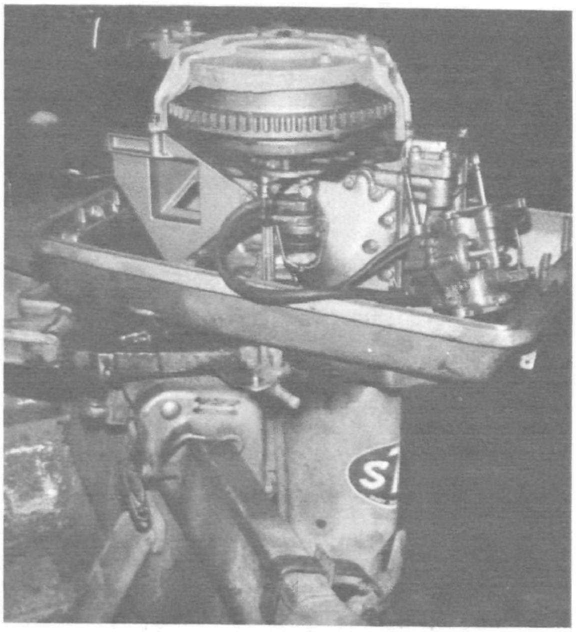
SECTION X

APPENDIX B

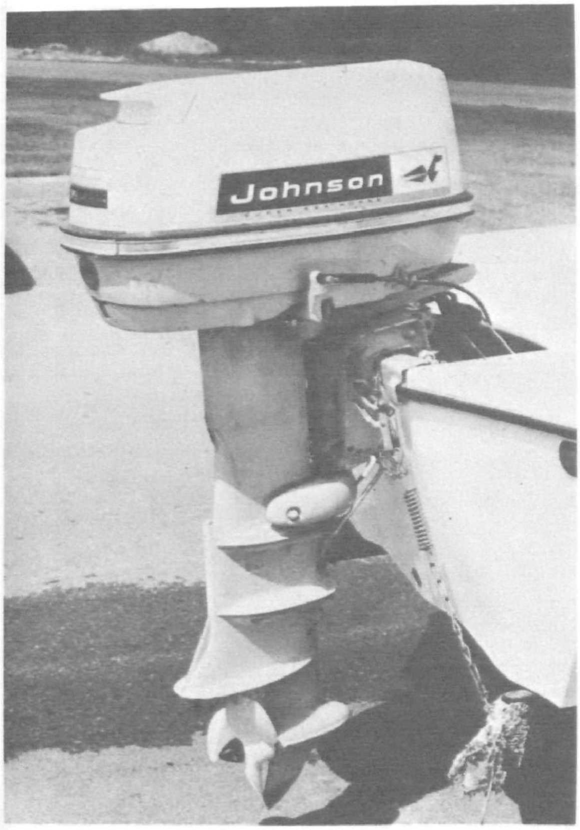
Photographs of Test Engines



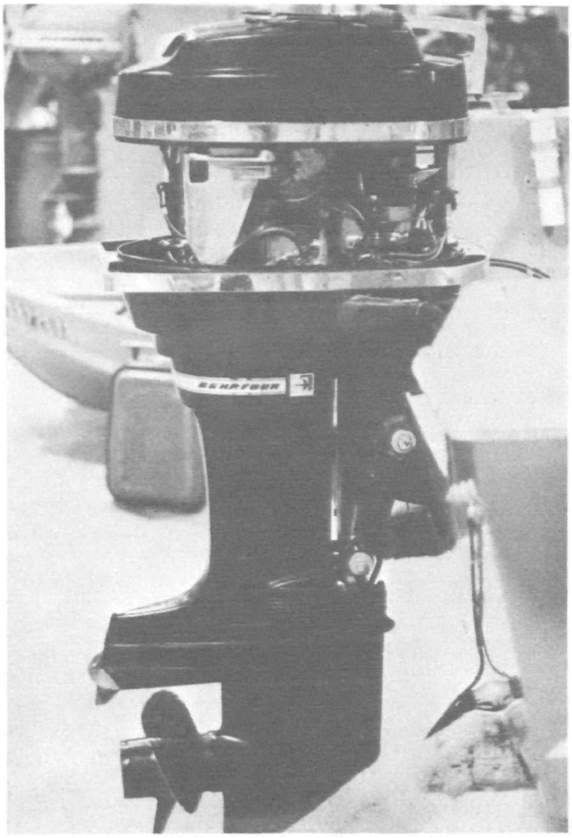
Engine No. 1. 1965 Johnson 9.5 hp



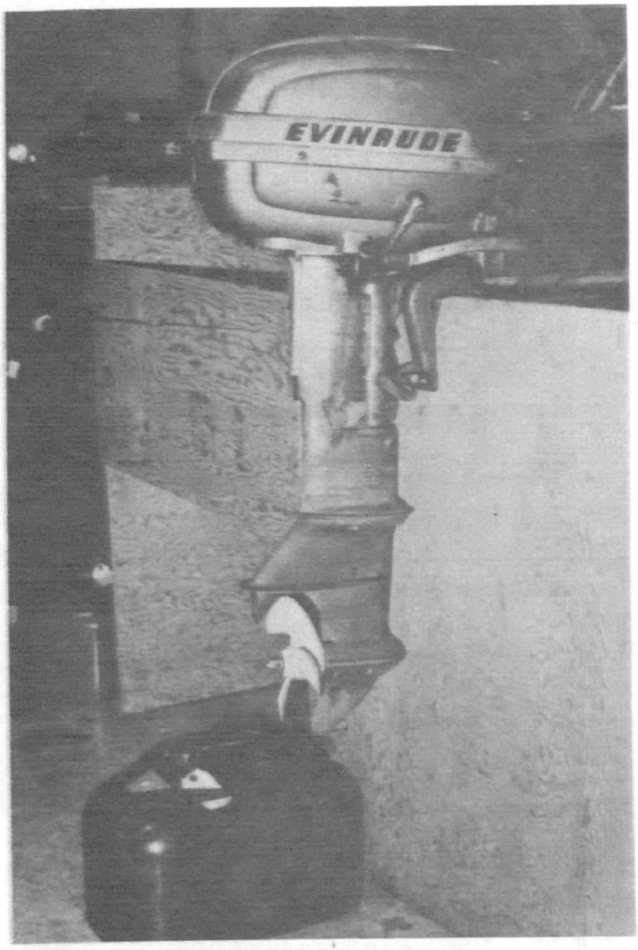
Engine No. 2. 1960 Evinrude 18 hp



Engine No. 3. 1966 Johnson 33 hp



Engine No. 4. 1965 Mercury 65 hp

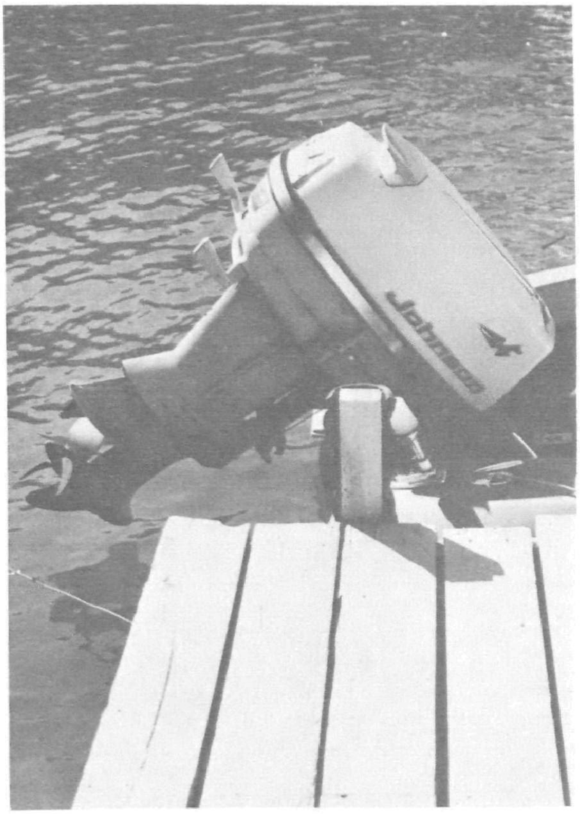


Engine No. 5. 1954 Evinrude 15 hp

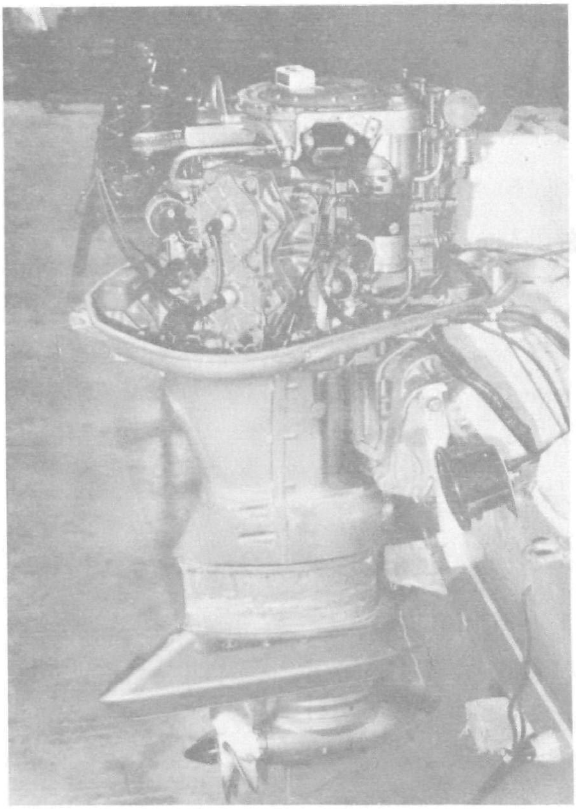
Engine No. 6. 1965 Sea King 50 hp

Engine No. 7. 1959 Mercury 45 hp

Engine No. 8. 1968 Johnson 40 hp

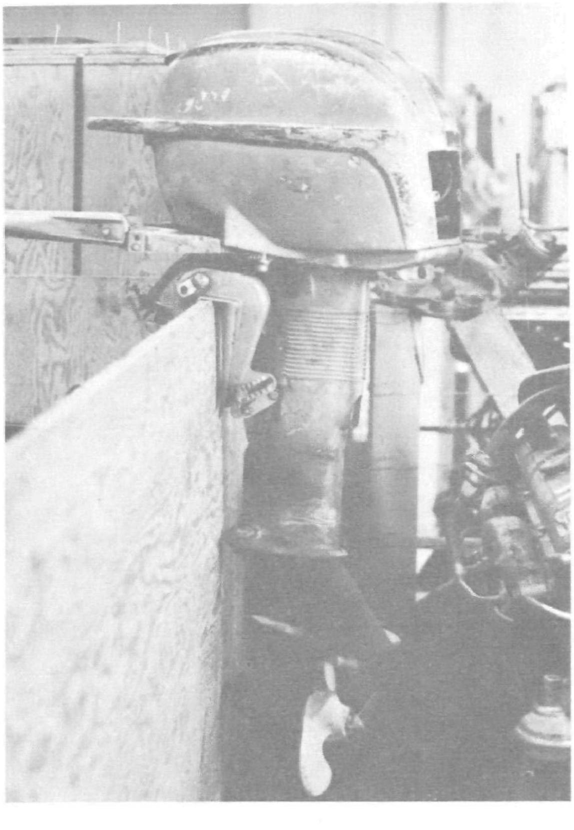


Engine No. 9. 1961 Johnson 40 hp



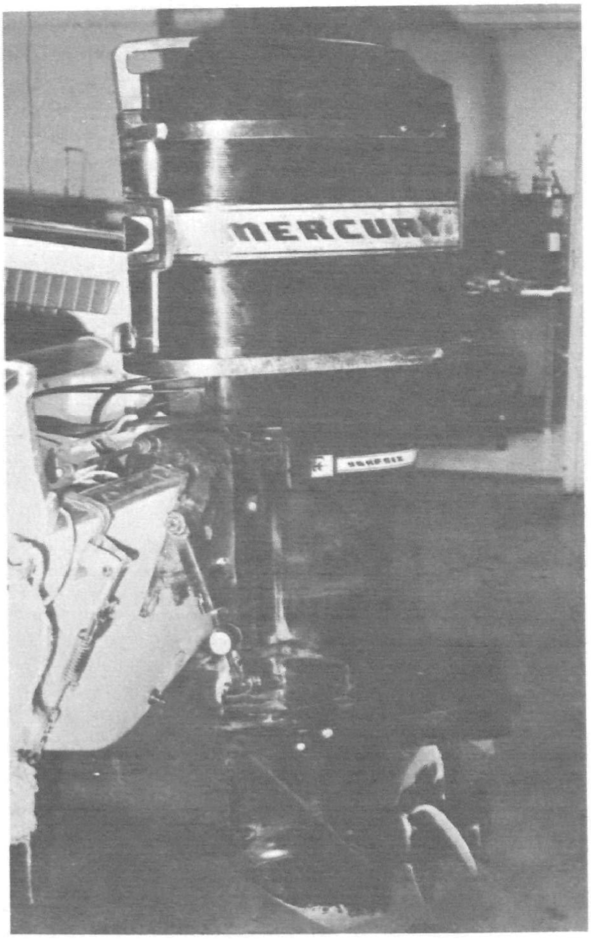
Engine No. 10. 1967 Evinrude 80 hp

Engine No. 11. 1971 Chrysler 55 hp
No Photo Available
Similar to Engine 20

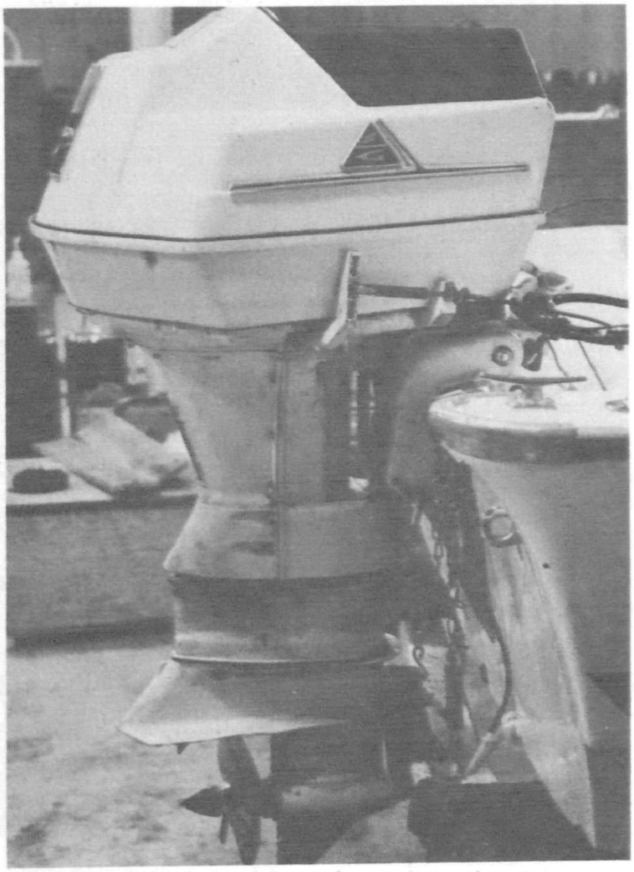


Engine No. 12. 53 Johnson 10 hp

Engine No. 13. 1967 Johnson 33 hp

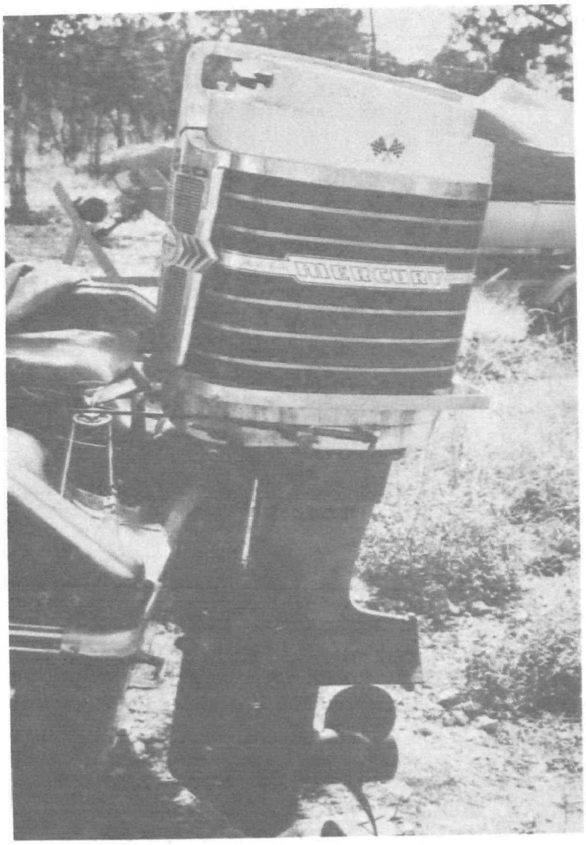


Engine No. 14. 1968 Mercury 95 hp



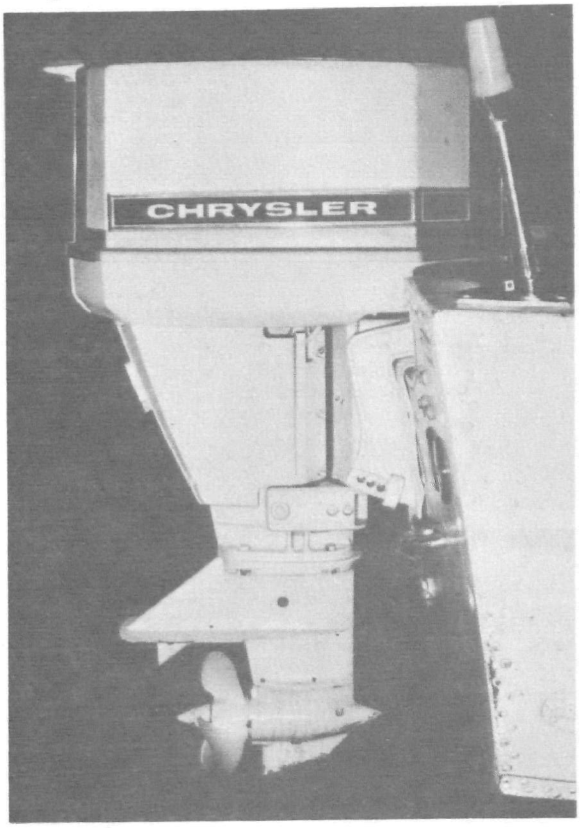
Engine No. 15. 1963 Gale 60 hp

Engine No. 16. 1964 Mercury 65 hp
No Photo Available
Similar to Engine 4



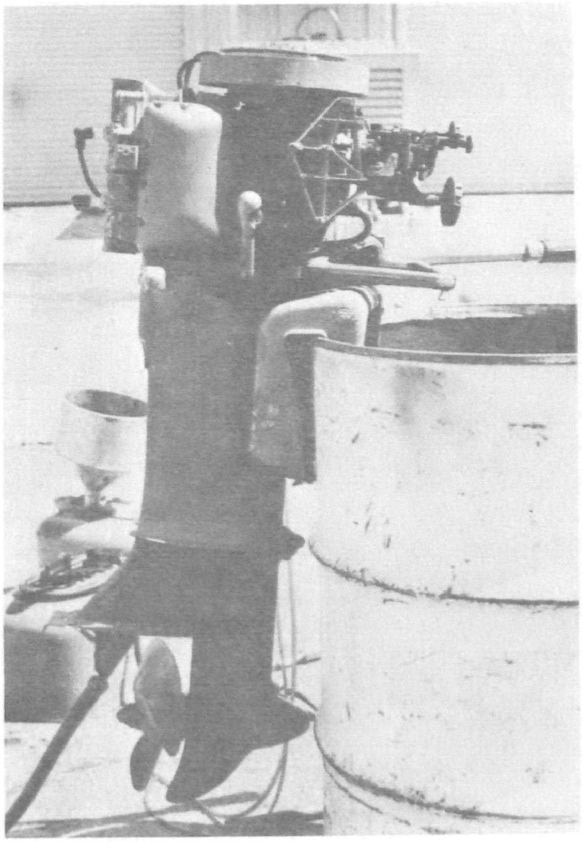
Engine No. 17. 1968 Mercury 85 hp

Engine No. 18. 1968 Evinrude 85 hp

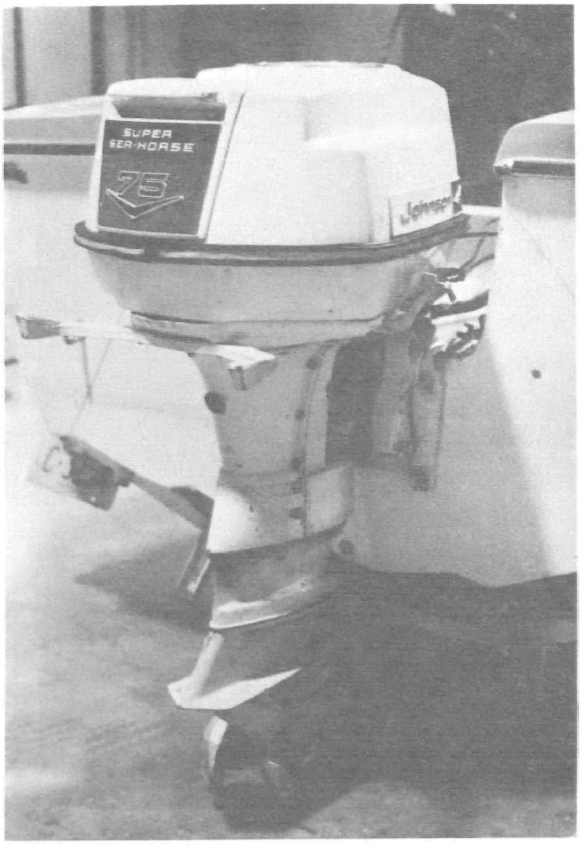


Engine No. 19. 1971 Chrysler 45 hp

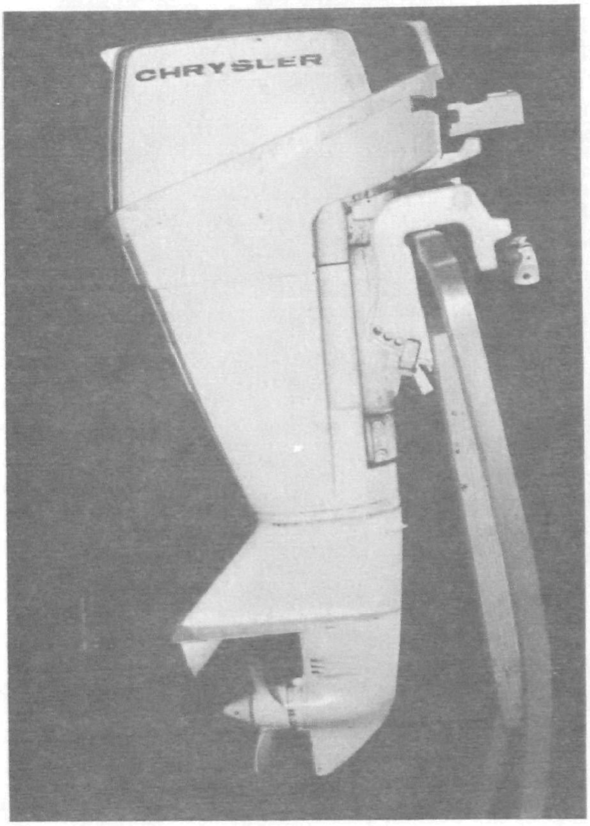
Engine No. 20. 1968 Sea King 45 hp



Engine No. 21. 1953 Johnson 25 hp



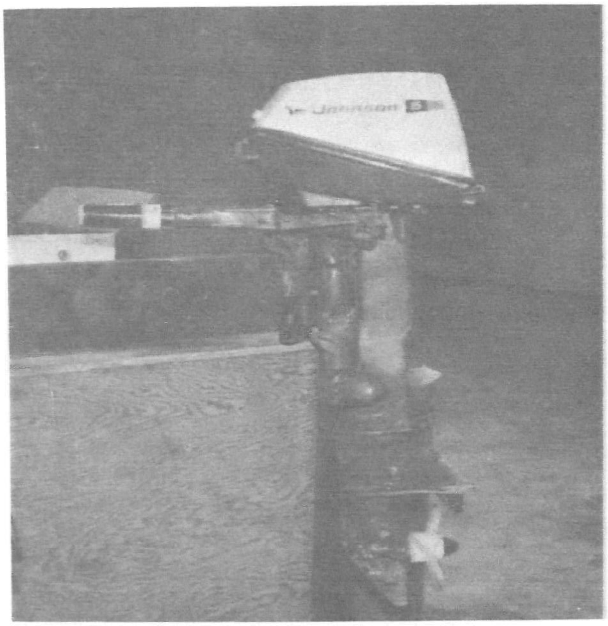
Engine No. 22. 1960 Johnson 75 hp



Engine No. 23. 1970 Chrysler 5 hp

Engines No. 24, 27, 28 and 34
No Photos Available
Similar to Engines 25 and 35

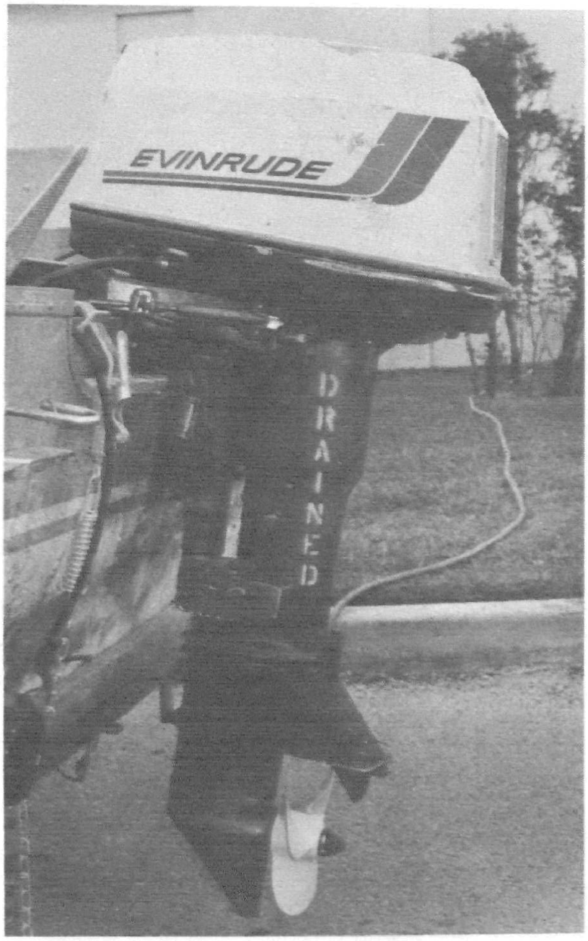
Engine No. 25. 1971 Johnson 9.5 hp



Engine No. 26. 1970 Johnson 6 hp

Engine No. 29. 1967 Mercury 6 hp

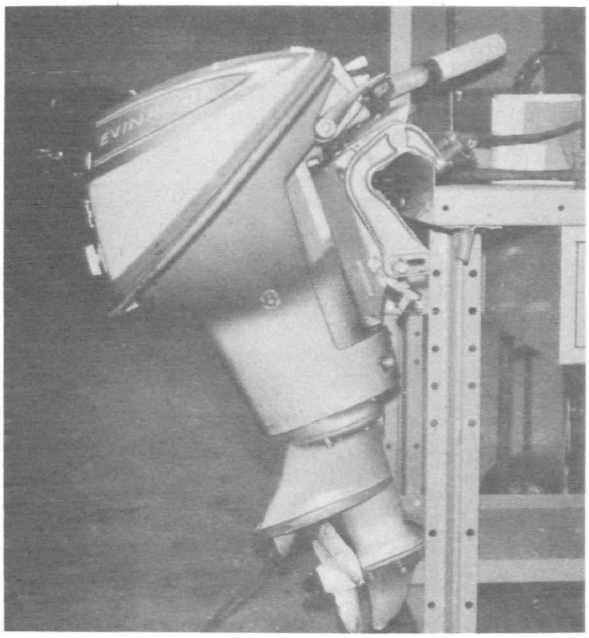
Engine No. 30. 1971 Mercury 9.8 hp



Engine No. 31. 1972 Evinrude 18 hp

Engine No. 32. 1971 Chrysler 35 hp

Engine No. 33. 1966 Johnson 40 hp



Engine No. 35. 1964 Evinrude 9.5 hp

SECTION XI

APPENDIX C

Statistical Calculations

Comparison of population means using Student's "t" distribution . . .

Comparison 1. Chrysler population vs Mercury population, mean composite drainage as percent of fuel consumed.

Chrysler	Mercury
$\bar{x} = 1.78$	$\bar{x} = 0.50$
$n = 6$	$n = 5$
$S = 3.13$	$S = 0.18$

$$\hat{S} = \sqrt{\frac{n_1 S_1^2 + n_2 S_2^2}{n_1 + n_2 - 2}} = 2.56$$

$$S_D = \hat{S}\sqrt{\frac{n_1 + n_2}{n_1 n_2}} = 1.55$$

$$t = \frac{\bar{x}_1 - \bar{x}_2}{S_D} = 0.83$$

$H_o: \mu_1 = \mu_2$

ν = degrees of freedom = 9

from table: $t_{0.975} = 2.26$ (0.05 level)

$t_{0.80} = 0.88$ (0.40 level)

Conclusion: accept H_o at 0.05 level of significance
accept H_o at 0.40 level of significance

Comparison 2. Chrysler - Mercury population vs OMC population, mean composite drainage as percent of fuel consumed.

Chrysler-Mercury	OMC
$\bar{x} = 1.20$	$\bar{x} = 5.35$
$n = 11$	$n = 17$
$S = 2.21$	$S = 4.20$

$$\hat{S} = \sqrt{\frac{n_1 S_1^2 + n_2 S_2^2}{n_1 + n_2 - 2}} = 3.68$$

$$S_D = \hat{S}\sqrt{\frac{n_1 + n_2}{n_1 n_2}} = 1.43$$

$$t = \frac{\bar{x}_1 - \bar{x}_2}{S_D} = 2.91$$

$H_o: \mu_1 = \mu_2$

ν = degrees of freedom = 26

from table: $t_{0.975} = 2.06$ (0.05 level)

$t_{0.995} = 2.78$ (0.01 level)

Conclusion: reject H_o at 0.05 level of significance
reject H_o at 0.01 level of significance

Calculation of 95 percent confidence intervals for mean composite drainage using Student's "t" distribution.

95 percent confidence interval for mean = $\bar{x} \pm S_{\bar{x}} (t_{0.975})$

where: $\bar{x}$ = sample mean
$S_{\bar{x}}$ = standard error of sample mean
$t_{0.975}$ = the appropriate statistic from Student's distribution at the 0.05 level of significance

non-OMC population: $\bar{x}$ = 1.20 percent ν = degrees of freedom = 10
(overall composite) $S_{\bar{x}}$ = 0.70 $t_{0.975}$ = 2.23
∴ 95% confidence interval is 0 to 2.76 percent

OMC population: $\bar{x}$ = 5.35 percent ν = degrees of freedom = 16
(overall composite) $S_{\bar{x}}$ = 1.02 $t_{0.975}$ = 2.12
∴ 95% confidence interval is 3.19 to 7.51 percent

non-OMC population: $\bar{x}$ = 3.00 percent ν = degrees of freedom = 10
(1500 rpm & lower) $S_{\bar{x}}$ = 0.73 $t_{0.975}$ = 2.23
∴ 95% confidence interval is 1.37 to 4.63 percent

OMC population: $\bar{x}$ = 17.2 percent ν = degrees of freedom = 16
(1500 rpm & lower) $S_{\bar{x}}$ = 2.84 $t_{0.975}$ = 2.12
∴ 95% confidence interval is 11.2 to 23.3 percent

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

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EPA-670/2-74-092

2.

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16. ABSTRACT

Crankcase drainage from 35 outboard motors was measured during normal operation on two lakes in the San Antonio area. The motors included a variety of sizes and brand names, and they were tested under prolonged constant-speed conditions as well as cyclic speed conditions designed to simulate user operation in the field. Four engines of the same group were also tested with a drainage intercepting and recirculating device. Drainage was measured by both mass and volume, and results were also computed in mass per unit time (g/hr) and percentage of fuel consumed by weight and by volume. Analysis of some fuel samples was conducted by gas chromatograph, including a few in which drainage was mixed with fuel by the recirculating device mentioned above. Photographic documentation of the test engines, the drainage systems, and test/measurement techniques was also obtained. Based on measurements obtained during this study and estimations on the current outboard motor population, a range for the national total crankcase drainage emissions was estimated. It was also found that the major causes of variation in drainage rates were engine type, engine operating speed, and differences from one engine to another of the same type (or a similar type).

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Boats	*Outboard motors	13B
Gasoline	*Water pollution sources	
*Water pollution	Oil pollution	
*Outboard engines	*Crankcase drainage	
Motor boats		

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