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USCG-74-2

Report No. CG-D-27-75

MARINE ENGINE-EXHAUST EMISSIONS TEST CELL

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NOVEMBER 1974

INTERIM REPORT

Prepared for

DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD
Office of Research and Development
Washington DC 20590

Technical Report Documentation Page

1. Report No. CG-D-27-75	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle MARINE ENGINE-EXHAUST EMISSIONS TEST CELL		5. Report Date November 1974
		6. Performing Organization Code
7. Author(s) Earl C. Klaubert, Robert A. Walter		8. Performing Organization Report No. DOT-TSC-USCG-74-2
9. Performing Organization Name and Address U.S. Department of Transportation Transportation Systems Center Kendall Square Cambridge MA 02142		10. Work Unit No. (TRAIS) CG407/R4001
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation United States Coast Guard Office of Research and Development Washington DC 20590		13. Type of Report and Period Covered Interim Report January-December 1973
		14. Sponsoring Agency Code GDET-1

15. Supplementary Notes

This is project no. 4330.3/5.

16. Abstract

A marine engine-exhaust emissions test cell for boat-size diesel engines (approx. 200 hp) and outboard engines was constructed as part of a project sponsored by the United States Coast Guard for the monitoring and control of emissions from marine sources. This report describes the salient features of the cell including its structural aspects and noise attenuating capabilities. The engine types to be tested are briefly outlined. The power train for testing outboard motors along with the instrumentation assembled for monitoring and controlling the various test engine operating parameters are discussed in detail. Techniques for handling the outboard engine-exhaust emission gas sample and the instrumentation for emission measurements are described.

17. Key Words Noise, noise attenuation, outboard motors, diesel engines, marine engines, exhaust emissions, emissions measurement	18. Distribution Statement DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 68	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

The test cell and equipment described in this report are used for measuring the concentrations of major pollutants in the exhaust gases of marine outboard and diesel engines. The outboard motors are representative of types used both on Coast Guard boats and in the civilian pleasure fleet. The diesel engines are of the type used by the Coast Guard for powering small boats and cutters and for driving electrical generators on ships.

This work is being performed by the Transportation Systems Center (TSC) of the U.S. Department of Transportation as one major task of a project sponsored by the Coast Guard Office of Research and Development. The Coast Guard Project Officer for FY1972-3 was Commander Robert J. Ketchel, and for FY1974-5 is Lt. Roswell W. Ard, Jr.

The primary purpose of this project is to determine representatives levels of pollutants in the exhausts of most classes of Coast Guard vessels, to assist the Coast Guard in complying with all pertinent regulations and air-pollution standards. Practical techniques for routinely monitoring vessel exhaust emissions on a periodical or continuous basis also will be investigated.

Outboard-motor exhaust emissions are being measured largely to provide publicly available data on typical emission levels of this class of engines. Currently over 8 million such engines, in sizes ranging from about one horsepower up to 150 horsepower, are in use in the United States. Relatively little testing of outboard-motor emissions has been done; most of the data which have been collected are proprietary to the manufacturers and are unavilable to either the public or the government. Furthermore, nearly all outboards which are known to have been tested were essentially new at the time such measurements were made (Reference 1). But outboard motors up to 15 or 20 years old are still in use in significant numbers in the pleasure fleet, and no comprehensive, systematic survey of the emissions pattern as a function of engine age is known to have been made. Legislation for the establishment and enforcement of emissions standards for both existing and future models of outboard motors has been proposed, although not yet enacted. Some of the proposals would involve the Coast Guard, as either proponent or enforcer of such standards (Reference 2). The data to be gathered in the task described in this report, while not a statistically valid sample of the entire pleasure fleet, will provide the Coast Guard, or any other agency involved, with at least some body of information upon which to base decisions.

We would like to acknowledge the cooperation, assistance and advice pertaining to techniques and equipment used in dynamometer testing of outboard motors contributed by Messrs. Henry Kuemin, Manager of Engineering Test, and Michael J. Boerma, Manager of Technical Services, Outboard Marine Corporation, Waukegan, Illinois; by Mr. Richard H. Lincoln, Manager of Environmental Engineering, Outboard Marine Corporation, Milwaukee, Wisconsin; and by Prof. David E. Cole, Automotive Laboratory, University of Michigan, Ann Arbor, Michigan. Valuable advice in the selection of materials of construction for sound attenuation was provided by Captain John E. Wesler, USCG, who was then Chief, Electromechanical Branch, TSC. Very significant economies in the construction of the test cell were realized through the generous cooperation of the U.S. Army Materials and Mechanics Research Center, Watertown, Massachusetts, in making available indoor space with adjacent utilities as a site for the cell. Administrative and engineering support and contract administration for design and construction were supplied by the Facilities Branch, Management Services Division, TSC. During the summer of 1973, valuable assistance in installation of test-cell equipment, preparation of computer programs for data reduction, and data analysis was rendered by Cadets William Braceland, William Hendrickson, and Michael Hunt of the Coast Guard Academy. Charles R. Hoppen and Richard A. Roberts, of TSC contributed immensely to getting the many pieces of equipment installed, operating, and producing data.

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1. INTRODUCTION

This report describes the present configuration and capabilities of the Engine Exhaust Emissions Test Cell and its associated equipment, which are operated by the Transportation Systems Center under the auspices of the USCG, and briefly the test program presently being conducted therein.

During the early planning stages of the current outboard-motor test program, established procedures for dynamometer testing of outboard motors were investigated. Project personnel visited the laboratories of the OMC Engineering Division, Outboard Marine Corporation (Waukegan, Illinois) and those of the Automotive Laboratory, University of Michigan (Ann Arbor, Michigan), to observe equipment and procedures and to participate in extensive discussions of this kind of work.

At both laboratories, it was strongly emphasized that some sort of acoustical enclosure would be necessary to contain the high noise levels encountered in engine testing. OMC personnel reported that sound meter readings up to at least 110 dBA (decibels, A scale) had been measured in dynamometer test cells with modern large outboard motors. The building in which we planned to conduct (and now are performing) our engine testing is very large (approximately 150 feet wide x 800 feet long x 45 feet high), essentially undivided internally and hence susceptible to reverberations, and partly occupied by other personnel. It was obvious that some sort of test cell affording an acoustical attenuation of 40 dBA or more would be needed for permitting the planned engine testing program to be conducted in the available location.

A minimum-cost test cell which would meet the specific requirements of the planned test program was designed. The materials of construction for acoustical control were selected upon the recommendations of Capt. John E. Wesler, USCG, who at the time was Chief of the Electromechanical Branch at TSC.* The ancillary features of the cell (other than utilities and ventilation necessary for test operations), such as a separate fuel-storage room and a carbon dioxide (CO_2) fire-extinguishing system, were provided to satisfy safety requirements associated with operation of a gasoline-fueled engine inside a building. The final architecutral and engineering design and specifications were prepared, and the cell constructed, under contracts administered by the Facilities Branch, Management Services Division, TSC.

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*Captain Wesler is now Chief of the Plans and Programs Division, Office of Noise Abatement, Office of the Secretary, U.S. Department of Transportation.

2. STRUCTURAL ASPECTS OF TEST CELL

2.1 LOCATION

The minimum-cost site with requisite utilities was found in space made available to TSC at the U. S. Army Materials and Mechanics Research Center (AMMRC), Watertown, Massachusetts. The test cell was erected inside Building 311, near the west end.

2.2 CONSTRUCTION

A floor plan of the test cell, and of the adjacent control and instrumentation area, is shown in Figure 1. Pictures of the test cell exterior are shown in Figures 2 (view from southwest) and 3 (view from southeast).

The basic structure of the test cell is ordinary hollow-core concrete block walls 8 inches thick with a heavy, self-supporting roof comprised of 8-inch-thick hollow reinforced precast-concrete roof planks. The cell has exterior dimensions of 20 feet x 13 feet 4 inch x 13 feet high. In lieu of a foundation, the walls were built across the end of a 20-feet x 32-feet steel platen (machine-base floorplate) 16 inch thick which is supported by a massive reinforced-concrete block. A portion of the platen not covered by the cell can be seen to the left of the cell in Figure 2; only 6 inches of the platen's 16 inch thickness projects above the surrounding floor. The platen's top surface has large T-slots parallel to the sides of the platen on 2-foot centers in both directions; these slots can be seen in Figure 2. This slotted platen provides a very solid, flat, convenient surface for mounting and securing our equipment. The cell has one 2-feet x 2-1/2-feet viewing window in each long wall; each window is double-glazed with inner 3/8-inch and outer 1/4-inch plate glass spaced about 6 inches apart for noise attenuation. A steel beam secured to the cell roof along the length of the cell carries a trolley-mounted half-ton chain hoist which is used for handling heavy outboard motors and for positioning equipment.

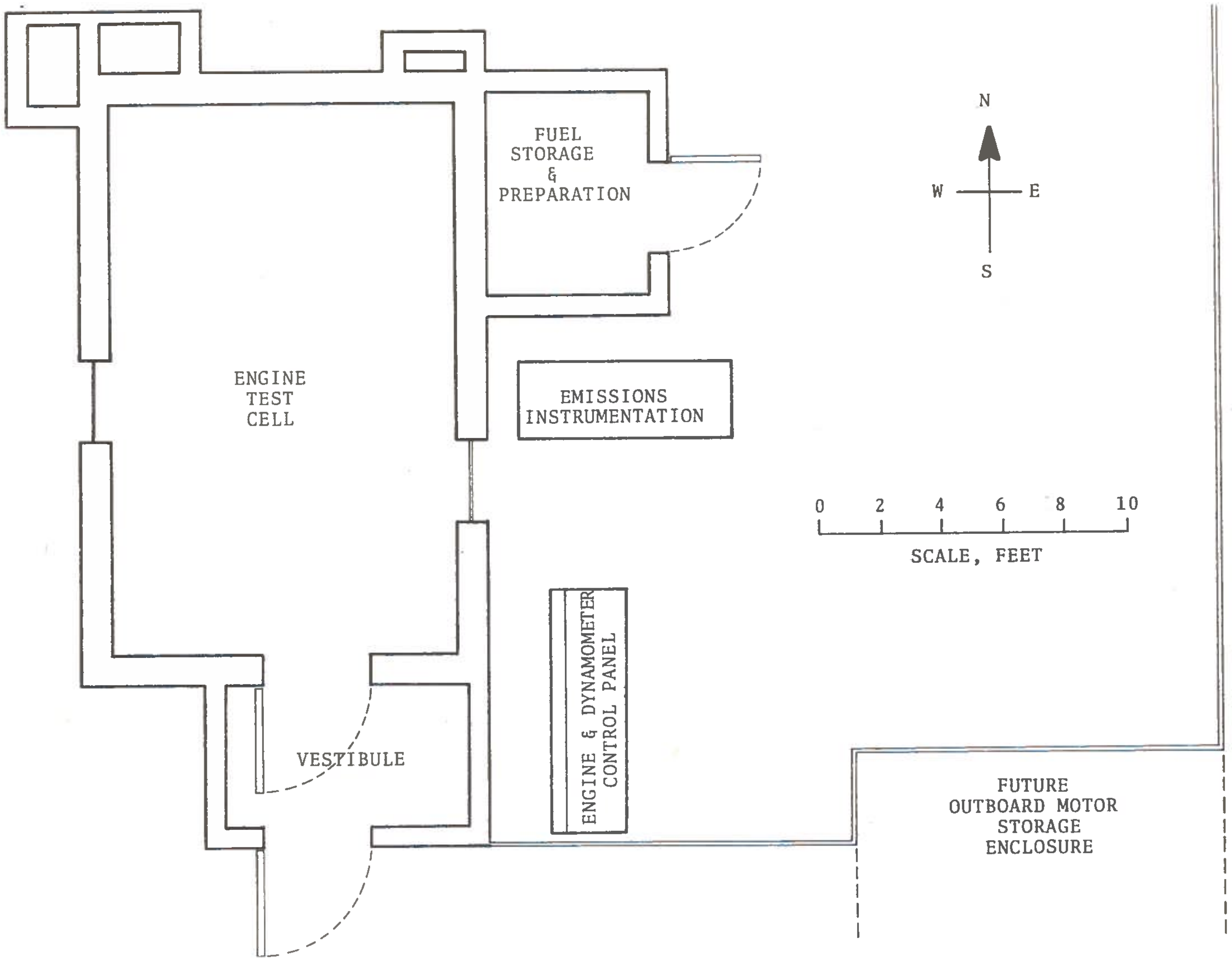

Figure 1. Floor Plan of Engine-Exhaust Emissions Test Cell

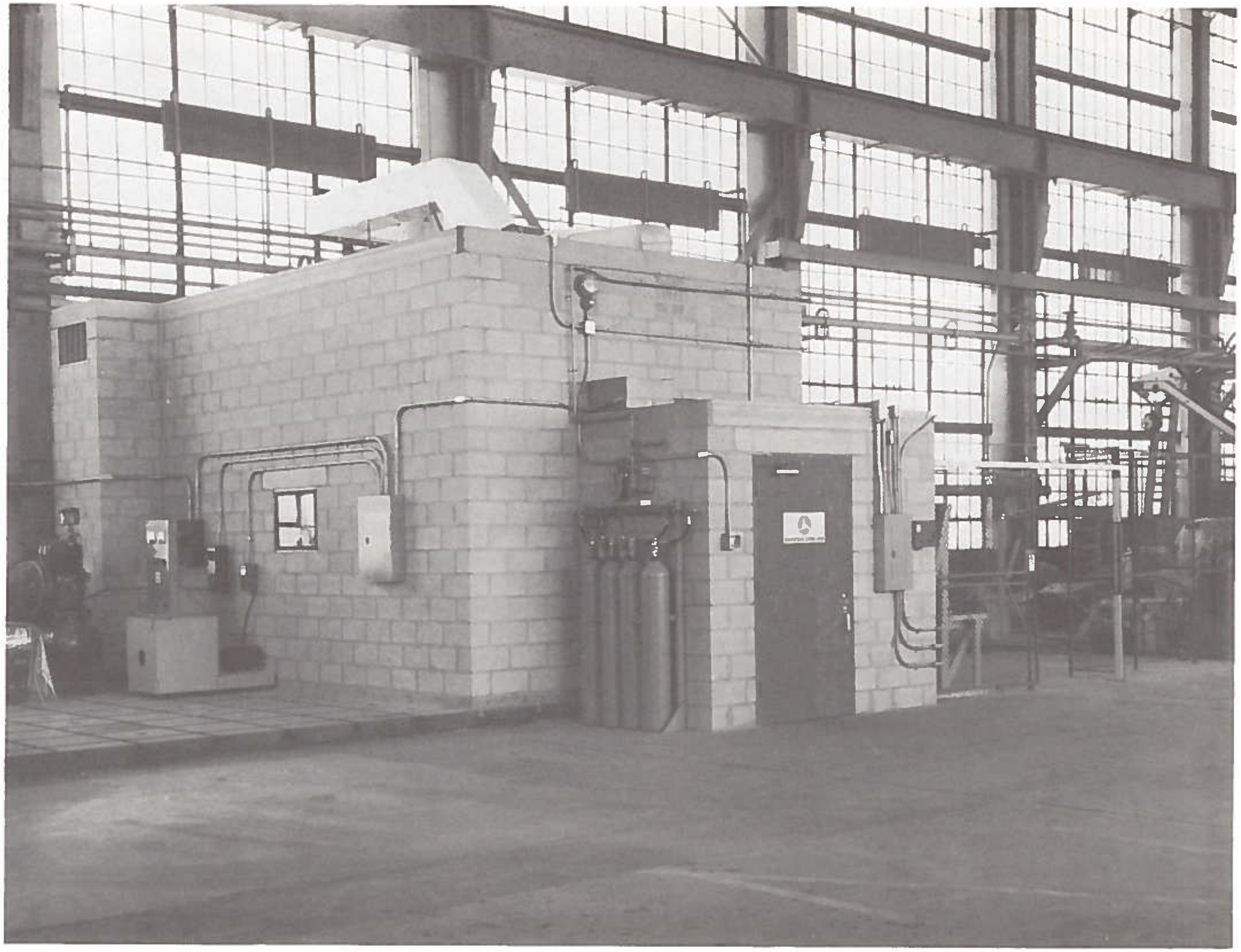

Figure 2. Exterior View of Test Cell from Southwest

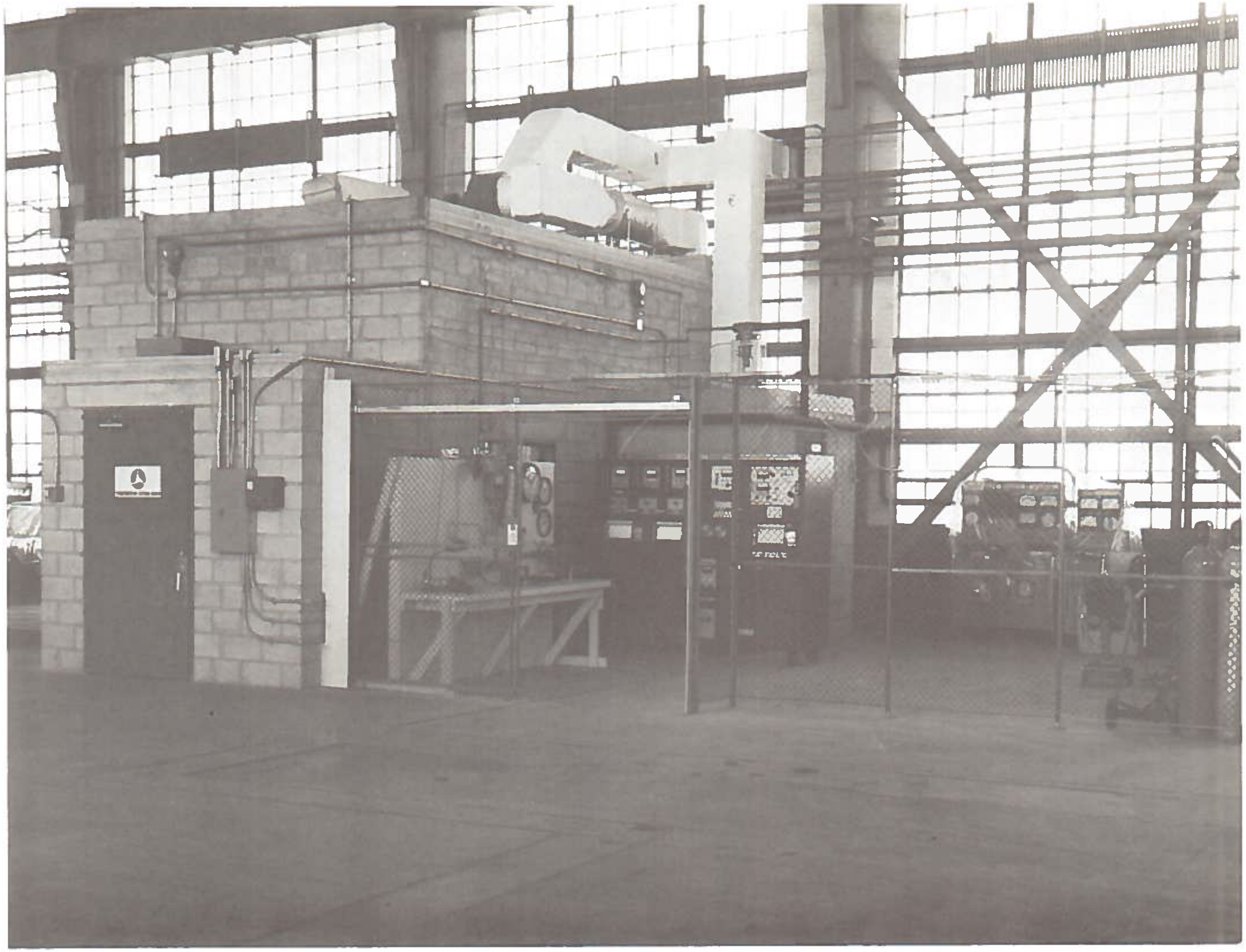

Figure 3. Exterior View of Test Cell from Southeast

The cell is entered through a single "sound-proof" door 7 feet high x 3 feet 6 inches wide, clear-opening. However, to control engine noise during entry or exits, this door is enclosed by a concrete-block vestibule equipped with a conventional metal outer door. This outer door has the same clear opening as the inner door and is directly in line with the inner door.

Engine exhaust and cell air are withdrawn from floor level at one rear corner of the cell, up a concrete-block noise-attenuating chimney, and through an acoustical silencer to a two-speed fan on the cell roof which discharges to the outside of Building 311, about 14 feet above ground level. Make-up air to the cell is drawn from the interior of Building 311; it enters the top of a two-pass chimney, passes down and then up through fiberglass-lined passages, and enters the cell at the upper corner of the rear wall diagonally opposite the exhaust exit port.

Against the outside of one long wall of the cell, at the rear corner, is a concrete-block fuel storage and preparation room 6 feet x 8 feet x 8 feet 8 inch high. Entrance to this fuel storage room is through a metal door opening outside the test cell; there is no communication with the cell interior, for fire-safety reasons. This storage room is ventilated by a separate, low-capacity explosion-proof fan which operates continuously; it too discharges outside Building 311 about 14 feet above ground level.

Reverberation and the buildup of standing acoustical waves within the test cell are minimized by the use of a "soft" interior lining. The walls and ceiling are faced with 3-1/2-inch-thick fiberglass acoustical insulation batts; the bare fiberglass is exposed to the cell interior. On the walls, the insulation is supported and protected from personnel contact by 4-inch-deep channels formed of heavy-gage galvanized expanded-metal mesh. Figure 4 shows a portion of an interior wall lined with this material.

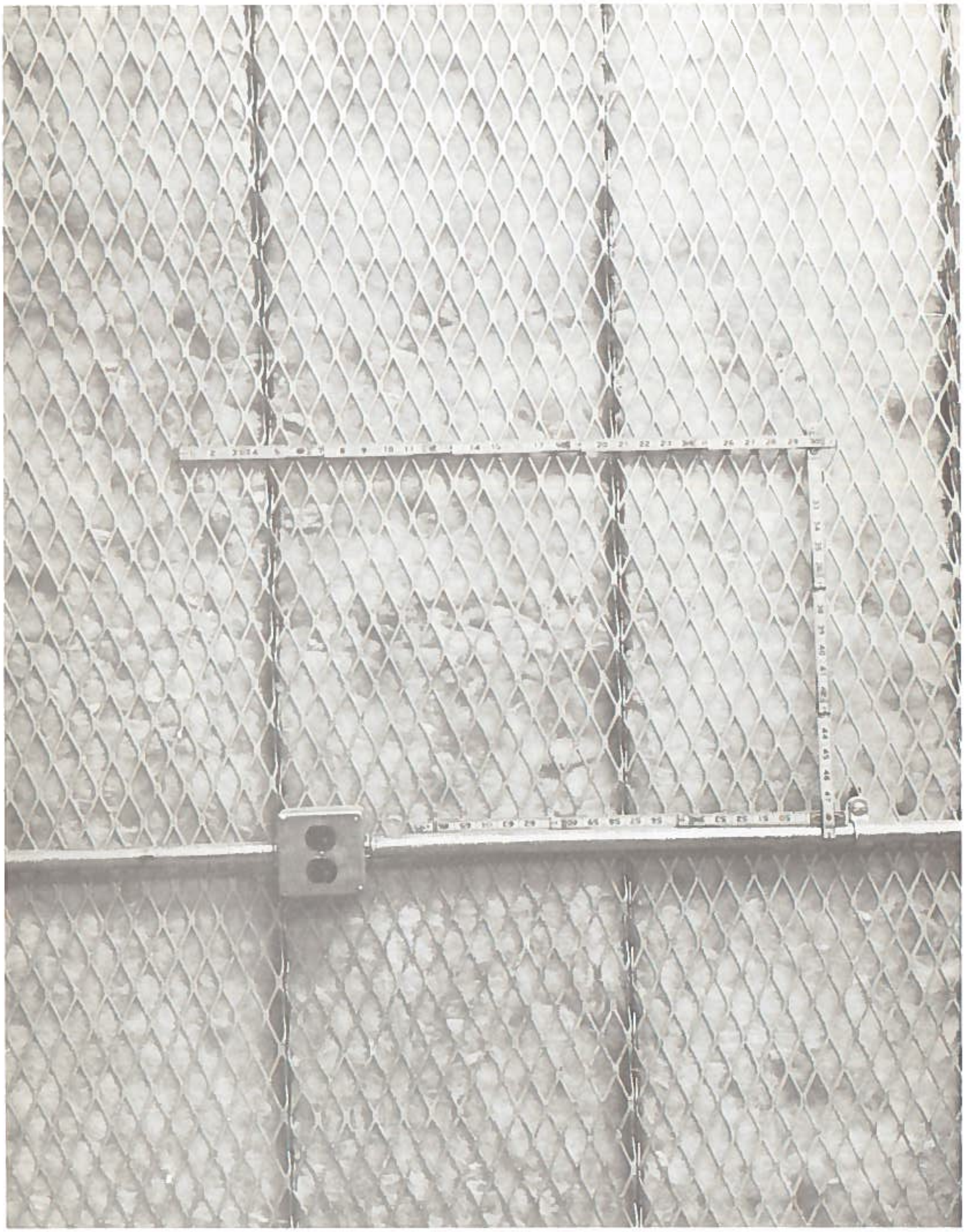

Figure 4. View of Interior Cell Wall "Soft Lining"

2.3 UTILITIES

Water and electrical power are drawn from mains in Building 311 adjacent to the test cell; the total consumption of each is measured by an appropriate meter. Cooling water from the dynamometer and from the engine on test is collected in a sump and pumped to an adjacent drain in Building 311.

Heat for the test cell and adjacent areas is provided by the heating system for Building 311, since the test cell and its air intake are located wholly within 311.

2.4 FIRE-PROTECTION SYSTEM

It is intended to operate the engines only within their recommended performance envelope during testing, but fire is always a possibility when gasoline-fueled engines are operated inside a building. Furthermore, operations require that one drum (up to 55 gallons) of gasoline be stored in the adjacent fuel-storage room. A CO_2 fire-extinguishing system was therefore installed; it will flood both the test cell and the fuel storage room simultaneously in the event of a fire. The system may be actuated either automatically, by means of ceiling-mounted thermostats in both protected areas, or manually, by actuators outside both protected areas or by the trip devices built into the CO_2 release valves attached to the CO_2 storage tanks. The system is provided with 100% excess CO_2 capacity held in reserve for immediate secondary protection. The CO_2 storage tanks can be seen in Figure 2 outside the west wall of the vestibule.

2.5 SOUND-ATTENUATION MEASUREMENTS

Since the primary reason for building the test cell was to contain engine noise, preliminary tests of the cell's sound attenuation were made as soon as construction was complete. (Another reason for making tests immediately was to locate any serious noise leaks so the contractor could correct them; none were found.) The outboard-motor test mount, drive train, and dynamometer had not been installed at that point, and so could not be used for noise generation. A gasoline-engine-driven 1.5-kW electric generator was used as an alternative noise source; an electrical resistance load equal to full generator capacity forced the drive engine to operate at power output. The engine was not equipped with a muffler for this test. Sound-level measurements were made made inside and outside the cell with a calibrated sound-level meter. Following is a summary of the most important observations.

Location	Sound Level, (dBA)
Inside cell, 1 foot from engine	106
Inside cell, at east wall (ca. 6 feet from engine)	100
Outside cell, ca. 3 feet from east wall window	65
Outside cell, ca. 3 feet from west wall window	64
Outside cell, ca. 1 foot from vestibule outer door, both doors closed	61
Outside cell at end of test, engine stopped	60

It should be noted that this series of measurements was made near the end of the working day in Building 311 and ended just about when other operations ceased. Ambient noise level was not measured before starting the engine, and there may have been a gradual decline in ambient noise level due to cessation of other activities in the building during the test period. Ambient noise levels 3-5 dBA or less below the noise level being measured could be expected to add perhaps 1-2 dBA to the measured level, because of the logarithmically additive nature of noise.

In any case, the effectiveness of the cell in containing engine noise was clearly demonstrated. In layman's terms (especially for those not accustomed to interpreting dBA numbers), cell performance can be described thus: conversation outside the cell at normal voice levels was completely unaffected by the attenuated engine noise; in fact, it was necessary to stop talking and listen rather carefully, at 3 feet from the wall, to be sure the engine was still running. A glance through the window to see the engine vibrating vigorously confirmed engine operation.

One design innovation in the cell merits a note, since it may be of use to others. The "acoustical stuffingbox" was used for removing, replacing, or adding to the numerous sample lines, control cables, signal leads, etc. passing through the test cell wall. Since some of the lines have enlarged non-removable fittings on both ends, rigid conduit with packing and mastic sealing (a conventional approach) seemed highly undesirable. Instead, a two-inch-thick box was built out of two sheets of rubber. Both faces had openings the size of the core openings in the concrete blocks which had been laid on their side during wall construction to provide for wall penetration. The stuffingbox was sealed to the outer wall, and the openings were closed with 1/16-inch-thick gum rubber sheet supported on the outside surfaces by aluminum window screening; both materials were adhesive-bonded to the stuffingbox frame. Full-size openings were made in the screening, undersize ones were cut in the rubber, and the various lines were passed through both facings. The stuffingbox was then first filled with the largest commercially-available size of lead shot (No. 00 buckshot), which was settled to maximum packing density. The smallest commercially-available size of lead shot ("Dust) then was poured on top of the buckshot and settled to maximum packing density without disturbing the buckshot. Since both types of shot were supplied coated with graphite, the finer shot rained down freely through the interstices between the buckshot and increased the overall packing density in the stuffingbox by about 30 per cent. In addition, the relatively large spaces between buckshot were broken up into a much larger number of much smaller spaces with considerably increased surface/volume ratio and reduced mean free path--both of which are conditions that contribute to sound attention. This lead shot mixture for acoustical packing provided a granular, free-flowing quasi-liquid medium which was relatively easily retained, had very high density and acoustical absorbancies, and was inexpensive. There remained, however, the question of how well it would perform.

At the time of the acoustical tests reported on the previous page, the rubber facings and signal lines had not yet been installed, and simple corrugated-cardboard facings were used. When the engine was first started, only the cardboard facings had been installed. Sound levels inside and outside were measured; then the buckshot was added and external sound level remeasured; and finally, the dust shot was added. The results were as follows:

Location	Sound Level (dBA)
Inside cell, at inner facing	100
Adjacent to outer facing, cardboard only	86
Adjacent to outer facing, 00 buckshot added	73-77
Adjacent to outer facing, dust shot added	65-68

The same ambient-noise level conditions obtained for this test as for the first cell tests.

2.6 ADJACENT OFFICE/WORKROOM

AMMRC provided the project with an existing room about 16 feet x 27 feet, located approximately 40 feet from the test-cell entrance. This room is used as an office, for storage, and for mechanical and instrumentation setup and fabrication required for this project. A teletypewriter and acoustical coupler, together with the telephone, provide direct two-way access to a time-shared computer which performs immediate reduction of engine test data after each run. This prompt analysis of each run not only provides the data reduction needed, but also permits immediate detection of possibly erroneous data of test procedures. Results which seem out of line with other tests can be repeated for verification or correction with minimum loss of time, which is especially valuable if the engine is to be removed from the mount following the test.

3. TEST-CELL INTERIOR

3.1 ENGINE TYPES TO BE TESTED

The bulk of the engine testing scheduled will be performed on outboard motors of the types to be found in the Coast Guard inventory and in the civilian pleasure fleet. Virtually all of these will be the common two-stroke-cycle variety; however, for comparison it is intended to test both a four-stroke-cycle engine of significant size (e.g., the "Bearcat" 85- or 55-horse-power-(hp) and a rotary-engine ("Wankel" type). The two-stroke outboards tested will be limited to branded products of the three major manufacturers (Mecury, Chrysler, and Marine Corporation--Johnson or Evinrude). Engines evaluated will date from current production back to about 1956, since the latter are still present in the pleasure fleet in significant numbers and will range in size from about 10 hp--the minimum our dynamometer can handle properly--to the largest available. One used engine, a 1959 50 hp V-4, was purchased both because its species was an important one, and because a "workhorse" was needed for developing our test procedures. All other engines used will be borrowed if possible, either from the Coast Guard, the Coast Guard Auxiliary, and the Power Squadron, or from private individuals, including TSC employees. All engines except brand-new ones will be tested first in the as-received condition; they will then be given a full factory-recommended tuneup by a franchised dealer for the appropriate make and retested to evaluate the effect of proper tuning on emissions.

The second type of engine to be tested, and one whose size governed certain design aspects of the test cell, is a diesel engine of about 200 hp used by the Coast Guard for auxilliary purposes such as driving electrical generators and powering small work boats. The prime point of interest with this engine will be the effects upon exhaust emissions, of injecting water into the exhaust pipe, as is done in horizontal exhaust pipes of boats and some cutters.

Initial work will deal with outboard motors; final details of the diesel engine effort have not been determined yet. Accordingly, the remainder of this report deals principally with the former type of engines.

3.2 OUTBOARD-MOTOR TEST POWER TRAIN

3.2.1 Outboard-Motor Test Mount

A universal support structure or test mount for outboard motors (OM's) was designed by project personnel. This mount was designed along the same basic lines as similar mounts used at OMC and the University of Michigan, but, certain special features were added to accommodate the wide variety of makes and sizes of OM's to be handled in rapid succession in our program. A fundamental design parameter was the height of the OM propeller shaft above the floor. This was dictated not by OM test requirements, but by the need to have the dynamometer shaft high enough to accommodate the 200-hp diesel engine; thus, 24 inches was selected as the horizontal centerline height for the entire drive train. The mount had to provide precise positioning of OM's with either short shanks (15-inch nominal transom height) or long shanks (20-inch transom height). Furthermore, the mount had to maintain the OM rigidly in the finally-adjusted position (within tolerances of about ±0.002 inches) to keep the propeller shaft properly aligned with the rigidly-supported drive shaft, in spite of the vibrations inherent in reciprocating-engine operation, with the power head supported to 5 to 7 feet above the floor. Accordingly, a massive, rigidly-braced design was necessary. (Some indication of this is evident in several of the figures to be shown later, and from the fact that the mount alone weighs nearly half a ton.) Figure 5 shows a front view of the mount with the 1959 Johnson 50-hp V-4 OM (long shank) in operating position. The fuel system and the electric-start panel are evident. The overhead chain hoist is attached to the OM purely for illustrative purposes; it normally is removed before operating the engine. The vertical scale board to the viewer's left of the mount is a 4 foot x 8 inch piece of

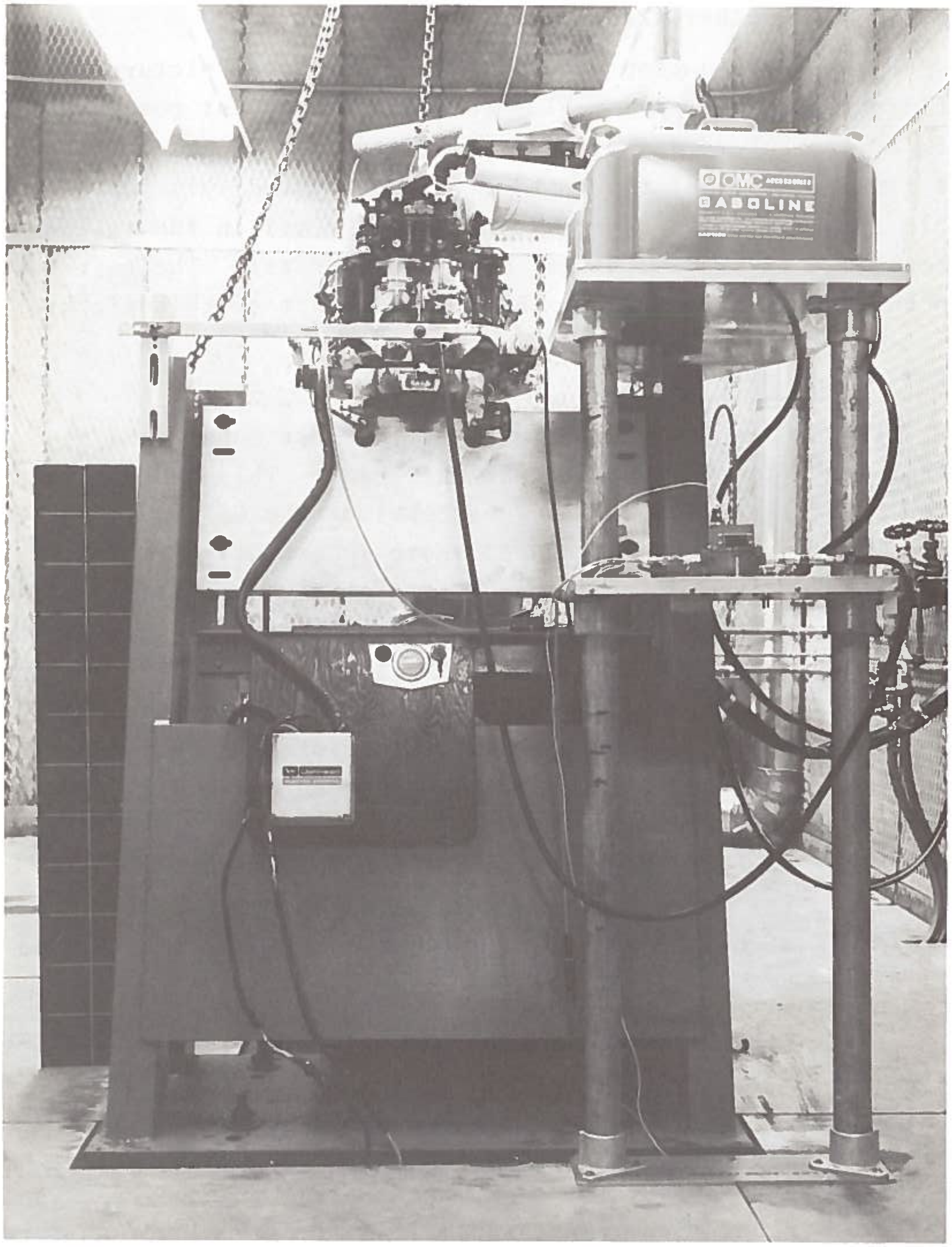

Figure 5. Outboard-Motor Test Mount Assembly with Engine Installed

plywood with an accurate 4-inch-square grid; it is positioned adjacent to the vertical rear channel of the mount (which will be visible in other figures).

Figure 6 is a composite assembly of several pictures taken from different positions and angles to present the best possible overall view of the entire drive train (most of which is described below). The limited width of the test cell necessitated this approach. (This figure will be referred to several times in the following discussions of the individual major components.) The test mount can be seen in side view at the extreme right of this picture.

3.2.2 Lower-Unit Tank

Attached to the rear channel of the test mount, and also to the platen (floor), is the lower unit tank. This tank contains water to cool the lower unit (gearcase) of the OM (i.e., to remove gear-friction and exhaust heat). More importantly, it serves to position the lower unit of the OM so that the propeller shaft is precisely coaxial with the mating drive shaft to the dynamometer. Accordingly, like the test mount, the lower unit tank structure is extremely rigid and is securely attached to the test mount, of which it actually is a component. The stiffening channels along one of the sides and across the head end can be seen in Figure 6. A two-piece cover for this tank encloses exhaust for withdrawal via the exhaust duct visible in Figure 6, and also confines water splashed by the drive shaft and engine exhaust. The nearer (starboard) half of the longitudinally split cover has been removed in this view.

Figure 7 is a view down into the lower unit tank (water was drained from the tank for better visibility). Along the inside of the tank wall can be seen a heavy channel with several jack screws passing through the inner flange. These screws, and similar ones on the opposite side of the tank, bear against the edges of a 1/2-inch-thick aluminum plate assembly called the lower unit restraint plate. A similar restraint plate assembly is fabricated for each OM to be tested. The plate provides intimate contact

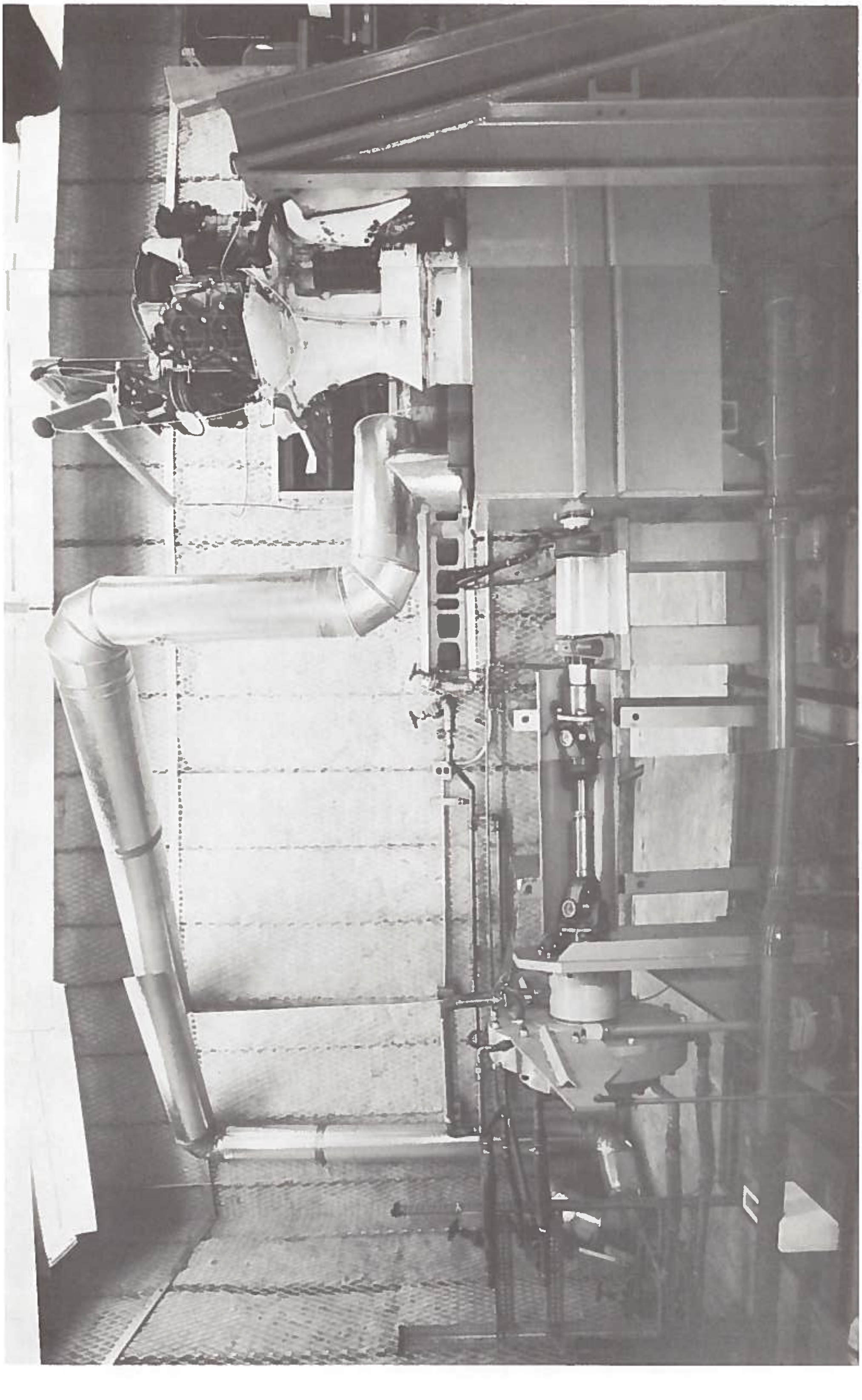

Figure 6. Composite Side View of Outboard-Motor Test Drive Train

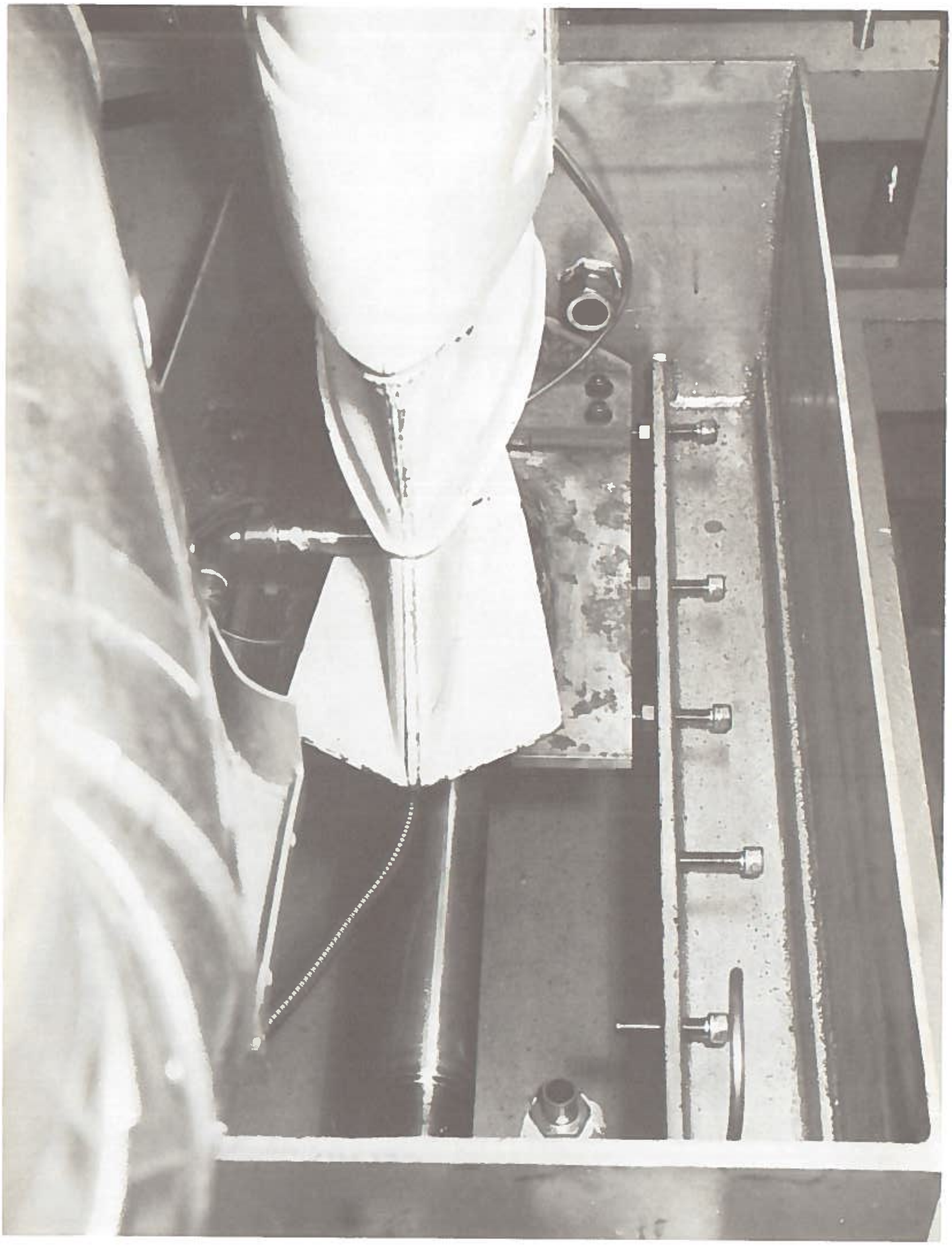

Figure 7. Top View into Part of Lower-Unit Tank

with and rigid guidance to the lower unit of the OM, and serves as the interface adapter between different OM's with varying configurations and the fixed jack screw assembly mentioned above. OM's with longer lower units will have longer restraint plates on which the jack screws nearer the aft end of the tank (nearer the bottom of Figure 7) can bear. The restraining plate is actually an assembly of two plates which separate along the centerline of the propeller shaft to permit assembly around the compound curves of OM lower units.

At the head end of the tank (top of Figure 7) can be seen part of a heavy steel angle bolted to the restraint plate. This angle is rigidly positioned at an adjustable distance from the head end of the tank by an axial jack-screw and clamp assembly. The position of this steel angle determines the fore-and-aft tilt of the OM needed to bring the propeller shaft vertically parallel to the drive shaft, and also fixes the longitudinal position of the propeller shaft. Horizontal "steering" of the propeller-shaft axis, and transverse horizontal positioning, are provided by the jack screws along the sides of the tank; however, the horizontal positioning by these jack screws must be performed in conjunction with similar positioning of the entire OM by the jack screws on the OM test mount which shift the "transom plate" onto which the OM is clamped. The height of the propeller shaft (and hence, of the OM) is adjusted by jack screws which slide the transom plate up or down the 15°-inclined guides of the test mount. When the transom plate has been finally positioned, it is secured to the test mount by heavy clamping screws which may be seen at the corners of the transom plate in Figure 5.

Precise and rapid positioning and alignment of the OM with respect to the drive shaft is made possible by a special gage fixture (not illustrated) which clamps onto the drive shaft. A bar mounted parallel to the drive shaft in this fixture carries a dial indicator which bears on the OM propeller shaft. If the drive shaft is rotated and slid toward and away from the OM, concentricity and parallelism of the OM propeller shaft can quickly be assessed, and the required changes in position can be measured and then observed during the process of adjustment. This gage fixture is then removed and the appropriate drive shaft extension (see below) installed.

Other features of the lower-unit tank which may be seen in Figure 7 are part of the recirculation system which pumps tank water past the OM lower unit at moderate velocity (simulating the motor's normal motion through the water when propelling a boat) to cool the lower unit. At the head end of the tank, above the restraint plate and steel angle, is one of four discharge fittings arranged on each side of the lower unit above and below the restraint plate. Water flows out of these fittings to induce motion past the lower unit. In the bottom of the tank, between the jack-screw channel and the drive-shaft extension, is one of two inlet fittings which supply tank water to the recirculation pump, from which it is delivered to the four discharge fittings. The recirculation pump can be seen under the tank in Figure 6. Between the pump and the discharge fittings, fresh water is added to the recirculation flow to displace water from the tank into the overflow drain (described further on) and thereby maintain a continuous flow through the tank (at a rate much lower than the recirculation flow rate) for heat removal.

Figure 8 shows a slant view into the aft end of the lower unit tank, behind the lower unit of the OM. The splash shroud has been removed, and the aft end of the port tank cover half has been raised slightly for improved visibility. Entering through the aft wall of the tank (at viewer's left of picture) is the axial-slide drive shaft (discussed below); this is the darker portion of the shaft, which extends to the groove. Between the drive shaft and the OM lower unit, and surrounding the OM propeller shaft, is a similar-sized but shinier piece of shafting. This is one of several drive-shaft extensions of various lengths which are used to adapt the system to OM's with different lower-unit lengths. The drive shaft is of stainless steel; the extensions are of an aluminum alloy.

At the forward end of the extension, the OM propeller shaft can be seen passing through what appears to be a collar of smaller diameter than the extension and into the extension. That "collar"

Figure 8. Slant View into Aft End of Lower-Unit Tank

actually is a flange on the end of an aluminum adapter insert which slips into the end of the drive shaft extension. (For OM's with very long lower units, the adapter slips into the end of the drive shaft itself, which has a recess of the same dimensions as the ends of the extensions.) These adapters are made of the same aluminum alloy as commercial propellers; they are broached by a firm which manufactures propellers for all makes of OM's and has the tooling in stock. The adapters thus provide an economical interface between one universal set of drive-shaft extensions and a wide variety of OM propeller shaft configurations (shear pins, rubber splines, etc.).

The unit surrounding the drive shaft at the aft end of the tank is the shaft seal cartridge assembly which prevents tank water from leaking out around the drive shaft. This seal is flush-cooled with a side stream of water from the recirculation system. The water enters through the smaller fitting at the extreme upper left, is carried to the seal through the 1/4-inch tubing adjacent to the tank aft wall, and leaves the seal and discharges into the tank through the bent tube which curves above the water surface near the starboard side of the tank at the aft end, over the starboard jack-screw channel. The discharge tube, which may be seen in both Figures 7 and 8, produces a backpressure on the flush water inside the seal that is slightly higher than the head of water against the seal inside the tank, and thereby ensures a leaktight seal.

The hose attached to the larger bulkhead fitting in the port wall of the tank carries cooling water to the OM. The lack of the high-velocity flow past the lower unit which would be experienced in boating, the aeration of the water in the tank, and the limited immersion of the OM lower unit combine to reduce the effectiveness of the normal OM cooling system operation, and thus may cause overheating of OM's, especially larger ones. Therefore, fresh cooling water is piped directly to an adapter attached to the OM in place of a cooling-system access port.

The vertical 2-inch pipe in the aft rear corner running down to the bottom of the tank is the overflow weir or standpipe which maintains a constant water level in the tank. The standpipe connects to the waste water drain system. Both OM cooling water and tank cooling water discharge into the drain via this standpipe. A bottom drain valve is provided for emptying the tank.

The exhaust sample probe (which is described below) can be seen in Figure 8 curving down out of the OM lower unit and up into the 8-inch T of the exhaust removal duct.

When an OM is being operated, both halves of the tank cover and the flexible splash shroud are installed. OM exhaust is discharged into the tank water and then collects in the tank, from which it is drawn off (together with some diluting air) by the exhaust system (shown in Figure 12). This diluting air enters the lower-unit tank through the space between the OM and the flexible splash shroud.

3.2.3 Axial-Slide Drive Shaft

Back on Figure 6, the axial-slide drive shaft can be seen emerging from the aft end of the lower unit tank and passing through two ballbearing pillow blocks which are bolted to a rigid support structure. This precision-ground stainless steel shaft is designed to slide axially in the pillow blocks when the locking rings of the blocks are released. Thus the shaft may move axially to allow the installation or removal of an OM or of a drive-shaft extension. When extreme displacements (greater than 5 inches) are required, the universal-joint drive shaft (described below) between the stainless-steel shaft and the dynamometer can be uncoupled from the stainless shaft and swund out of the way.

3.2.4 Universal-Joint Drive Shaft

In Figure 6, a double-universal-joint drive shaft can be seen connecting the stainless-steel drive shaft to the dynamometer. This universal-joint shaft allows up to 5 inches of longitudinal displacement of one end with respect to the other end, which isolates the dynamometer from axial loads and accommodates some of the variation in OM lower-unit lengths. The two universal joints protect the dynamometer from transverse forces and moments (except for the intended pure rotational torque) which could be caused by angular or parallel misalignment of the stainless steel shaft with respect to the dynamometer centerline.

3.2.5 Dynamometer

The last item in the power train shown in Figure 6 is the dynaometer. This is a dual-rotor waterbrake device. The two rotors mounted on a common shaft, are of different sizes to provide slightly-overlapping ranges of power absorption; load water is piped to the rotor housings independently and the rotors may be loaded individually or simultaneously. The dynamometer generates torque between rotor and housing by creating turbulent friction in the water contained between the two elements. (The power dissipated heats the water, and continuous operation is achieved by continually replacing the heated water with fresh cooling water.) Variations in torque at constant speed are achieved by changing the radial depth of the water annulus in the rotor housing, i.e., by altering the water flow rate. The performance envelope of the dynamometer is shown in Figure 9.

The rotor housing assembly of the dynamometer ("dyno") is supported in trunnion bearings and is free to rotate in response to braking torque applied to the rotor(s). This rotation is opposed, and the torque sensed, by a hydraulic load cell which converts force to pressure. The load cell is visible in Figure 6 on the near side of the dyno baseplate; it is attached to the torque arm of the housing by a vertical strut. If rotation in the opposite direction is required, the load cell can be moved to the opposite side of the dyno. Torque readout, in two ranges, is displayed on large gages on the control panel (described in paragraph 4.1) outside the test cell. Direct physical calibration of the torque-measuring system can be performed by hanging calibrated dead weights on the ends of the two torque arms of the dyno (a weight hangar is shown attached to the starboard arm in Figure 6).

The dyno water supply and drain piping can be seen behind the dyno in Figure 6.

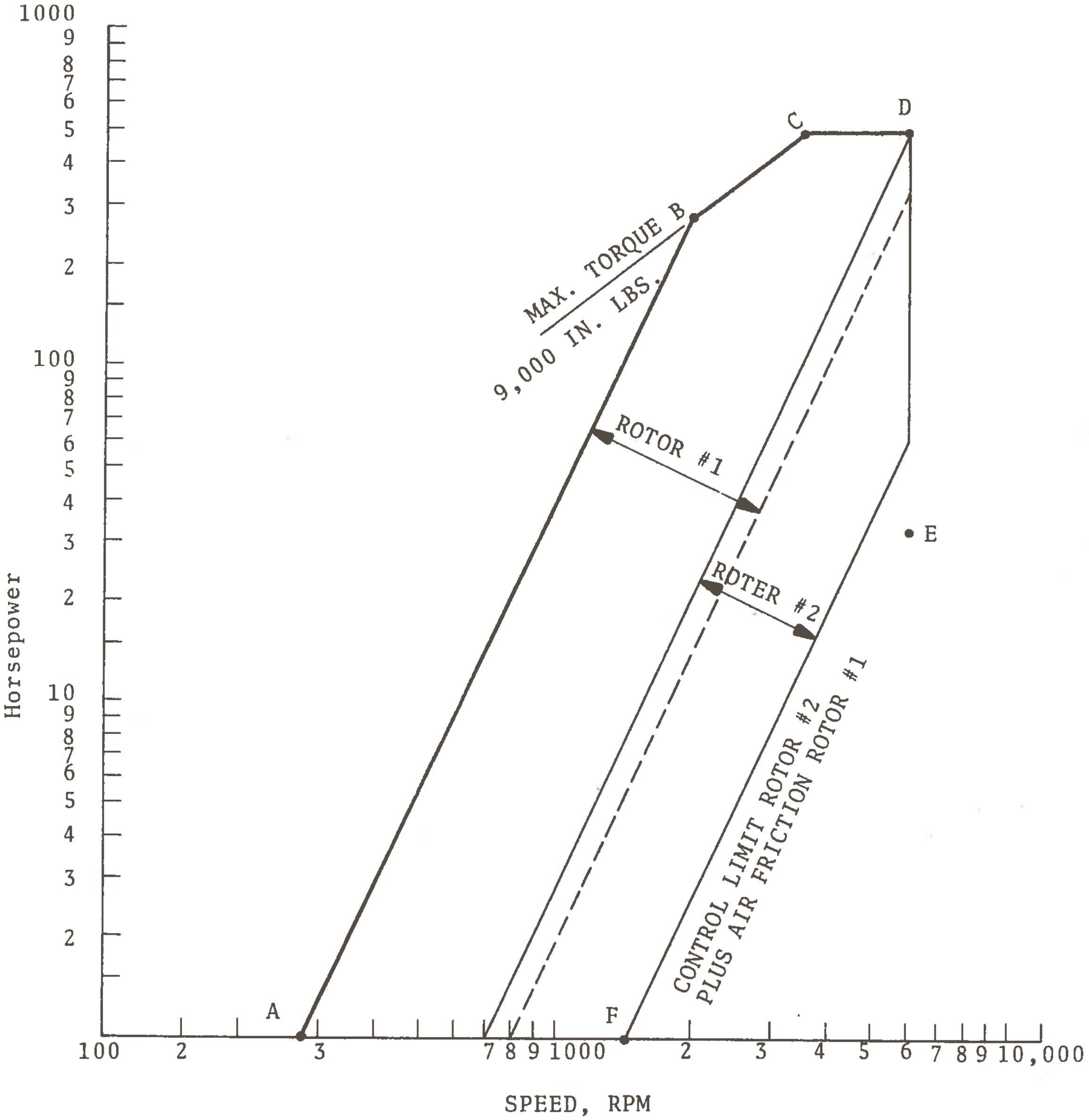

Figure 9. Performance Envelope of Dual-Rotor Dynamometer

3.2.6 Overall Cell Interior

Figure 10 shows an overall view of the test-cell interior from the starboard side of the drive train. The limited size of the cell necessitated the use of a wide-angle lens which introduced some distortion. In particular, the ceiling of the cell appears to be sloping up, while in fact it is flat. Also, the apparent size of the dyno, in comparison with the test mount tank and OM, is considerably exaggerated by the proximity of the dyno to the camera. This view of the ceiling shows the thermostat and one of the two CO_2 discharge nozzles of the fire-protection system in the test cell. The trolley beam for the chain hoist also is visible over the drive train.

In the east wall of the cell, on the port side of the drive train, several openings in the cell wall may be seen. These are concrete blocks which were laid on their sides during construction to provide passthrough ports for signal, sample, and control lines. Exhaust-sampling lines, heated and unheated, can be seen leading from the 8-inch exhaust T of the tank cover to one of these ports. Numerous instrumentation lines and the throttle remote-control cable pass through the farthest ports; considerable reserve space is still available. The 8-inch exhaust duct can be seen leading from the lower-unit tank cover toward the northeast corner of the cell, where it drops to the floor-level inlet to the exhaust chimney outside the cell wall. The window shown in the figure is the one through which operations are observed from the control and instrumentation area located immediately outside that wall.

Figure 11 is a view of the test-cell interior similar to that in Figure 10 except that it shows the port side of the drive train and certain features not visible in other figures. Many signal cables can be seen leading down the east wall and disappearing under the floor boards which cover the T-slots in the platen. When length limitations permit, cables are channeled through the T-slots to protect them from abrasion and to provide free access to the drive train. When a longer heated exhaust-sampling line is received,

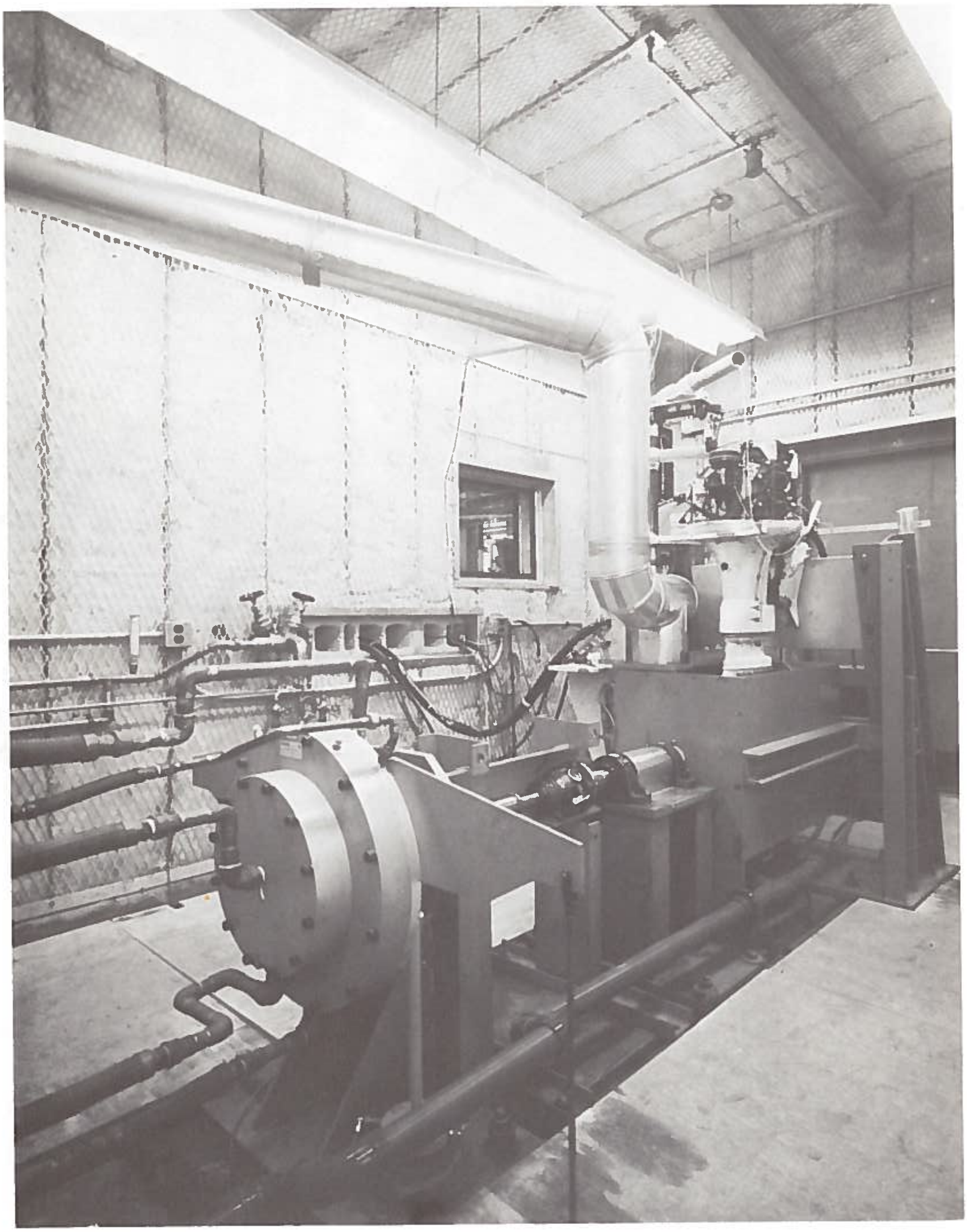

Figure 10. Test-Cell Interior, Starboard Side of Drive Train

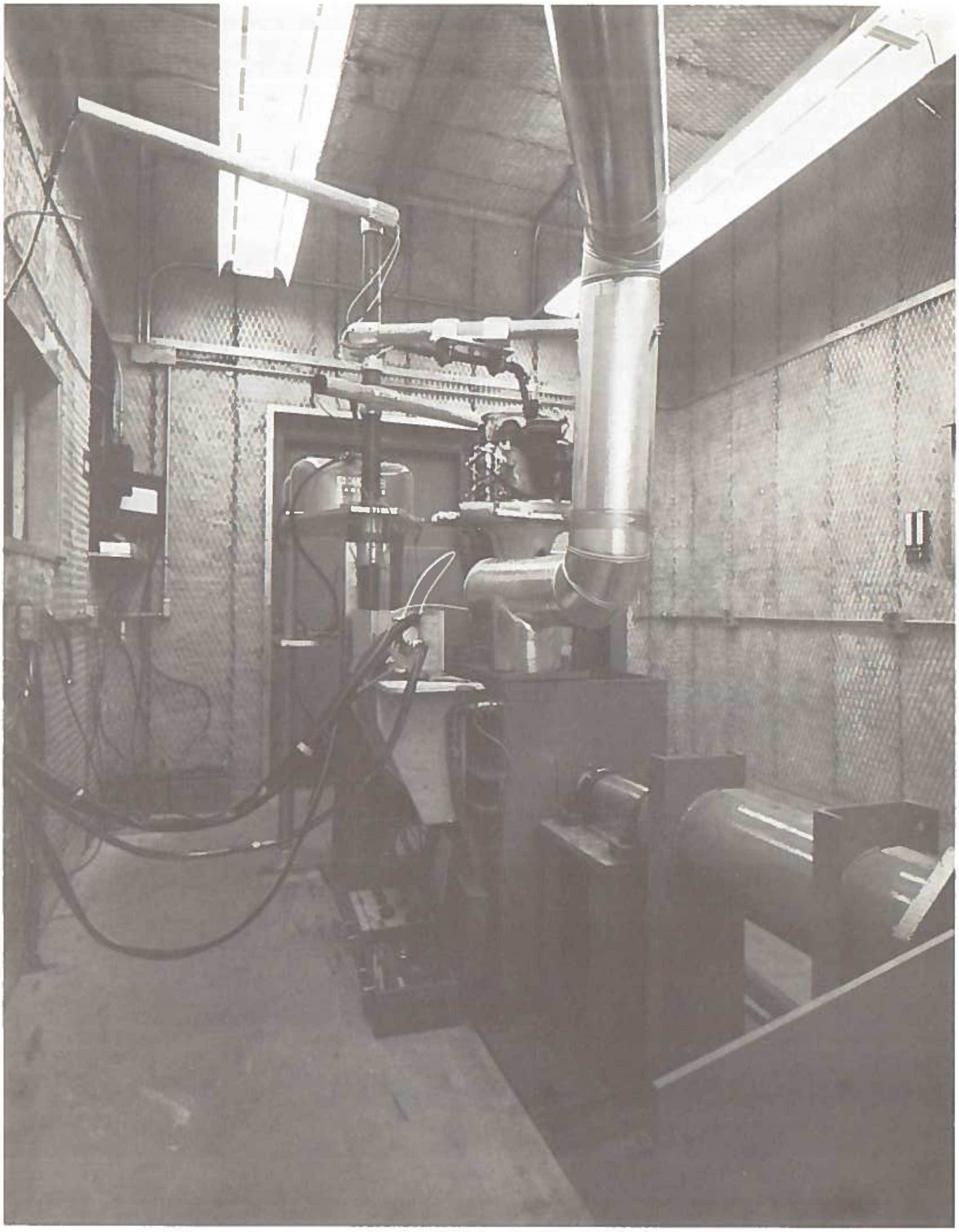

Figure 11. Test-Cell Interior, Port Side of Drive Train

it should be possible to put all lines under the floor and leave both sides of the drive train unobstructed.

Figure 11 shows the lower-unit tank cover assembled and the splash shroud installed between the tank cover and the bottom of the OM power head enclosure. The OM now is ready to run. (Other features of this view will be described in later sections of this report.)

3.3 OUTBOARD-MOTOR FUEL SYSTEM

The overall relationship of the OM fuel system to the OM on test can be seen in Figure 5. Two standard 6-gallon boat tanks are filled with the gasoline/oil mixture recommended for the specific OM and placed on the top shelf of the fuel-tank support. Fuel-delivery hoses are attached to the fuel selector valve (shown in Figure 12) by quick connect fittings. Fuel from the tank selected by the valve flows past the fuel-line vent valve to the fuel flow meter. The vent valve is used to bleed air from the fuel hoses when they are first attached to the selector valve; waste fuel from the vertical vent tube is collected in a container and discarded.

Attached to the fuel flowmeter by a quick-connect fitting is a delivery hose which leads to the OM. This final delivery hose is the only component of the fuel system which has to be changed to accommodate OM's of different makes which require snap-on fuel line connectors of various configurations. Replacement fuel hoses with appropriate OM connectors will be bought as needed and equipped with quick-connects to mate with the fuel flowmeter discharge fitting.

The fuel flowmeter provides dial readout of fuel quantity delivered to 99.99 gallons; a separate dial on top of the meter can be read to 0.001 gallons. The meter will recycle to 0.00 and continue counting. To provide remote readout, this meter has been fitted with an infrared emitter/detector and chopper wheel unit on the primary meter spindle which produces 77,760 electrical pulses per gallon of fuel delivered. These pulses may be counted for a short

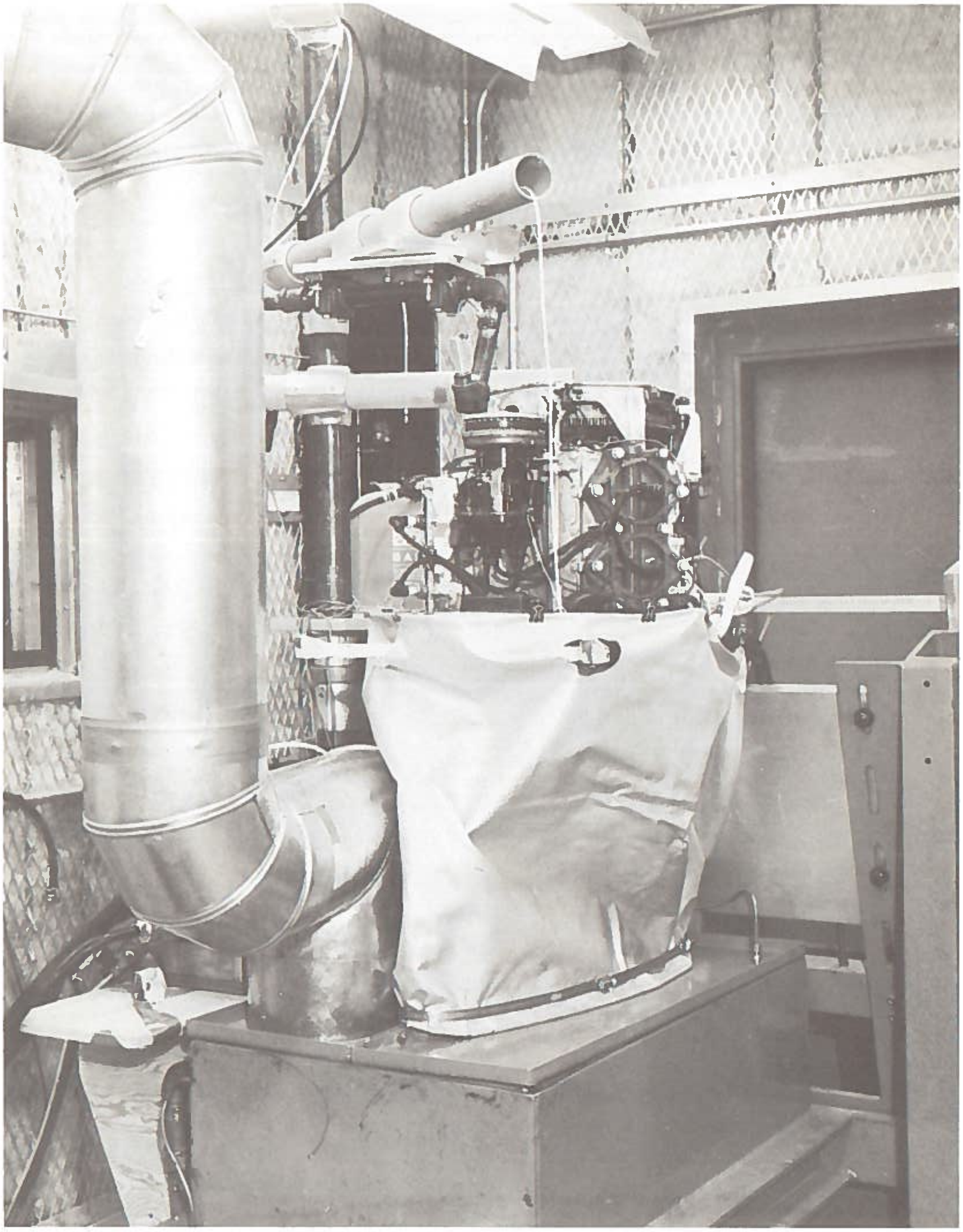

Figure 12. Outboard Motor on Test Mount, Ready to Run

known period of time (0.1, 1.0, or 10 sec) to indicate fuel flow rate, or may be input to a frequency-to-voltage module to provide an analog readout of flow rate; alternatively, they may be counted over a longer period of time to give a high-resolution electrical measurement of total fuel flow during that period. Fuel consumption over a period of time also can be determined, on a weight basis, by weighing the tank before and after a run.

The pressure drop across the fuel flowmeter is equivalent to approximately 15-20 inches head of gasoline. Therefore, to allow the OM to operate with normal fuel suction pressure on the fuel pump, the fuel tanks are evaluated above normal boat-floor position (with respect to the power head) by about that height, as may be seen in Figure 5.

In Figure 13, the input T to the fuel flowmeter can be seen to be fitted with a thermistor temperature probe. This probe permits continuous monitoring of fuel temperature.

3.4 Carbon Monoxide Monitor and DC Power Supply

Protection of personnel working in the test cell against accidental poisoning by carbon monoxide during or after engine operation was desired. This is provided by an aircraft-type CO monitoring instrument installed in the test cell, as shown in Figure 14. Air from the cell is drawn into a sampling tube positioned slightly above head level over the window in the east wall of the cell, and through the CO monitor, by a pump on the floor below the instrument. A portion of the sampling tube can be seen in Figure 14 emerging from behind the fuel tank and running to the monitor; the inlet end of this tube can be seen over the window, projecting from the wall, in Figures 10 and 11.

The CO monitor operates on 24 vdc, and draws several amps during warmup. Since at least one 12-V storage battery would be required anyway for electric-starting OM's, and two batteries and a charger were available, these items constituted a feasible and economical source of this power. In Figure 14, the charger can be seen mounted on the wall panel adjacent to the CO monitor,

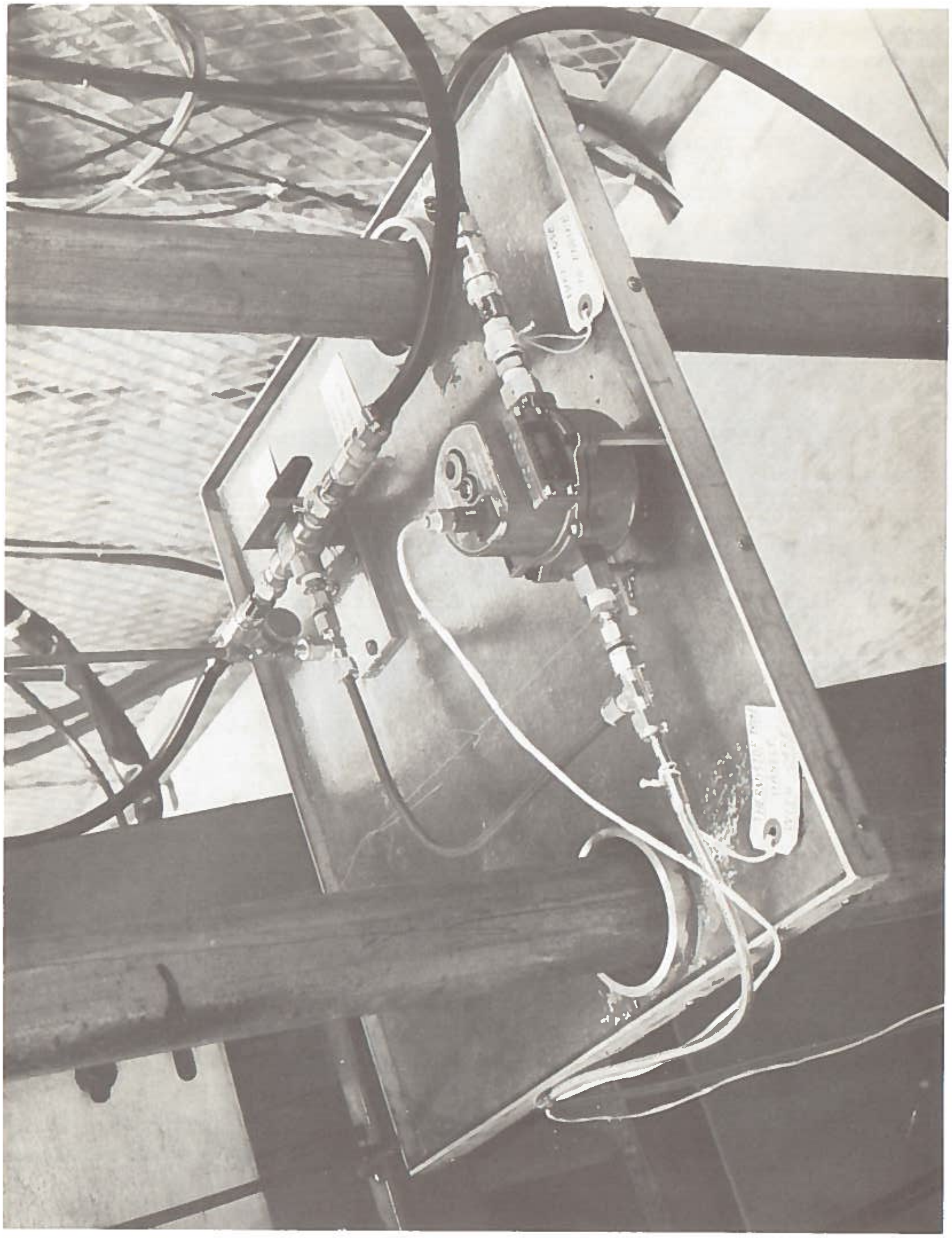

Figure 13. Closeup of Fuel Flowmeter Shelf

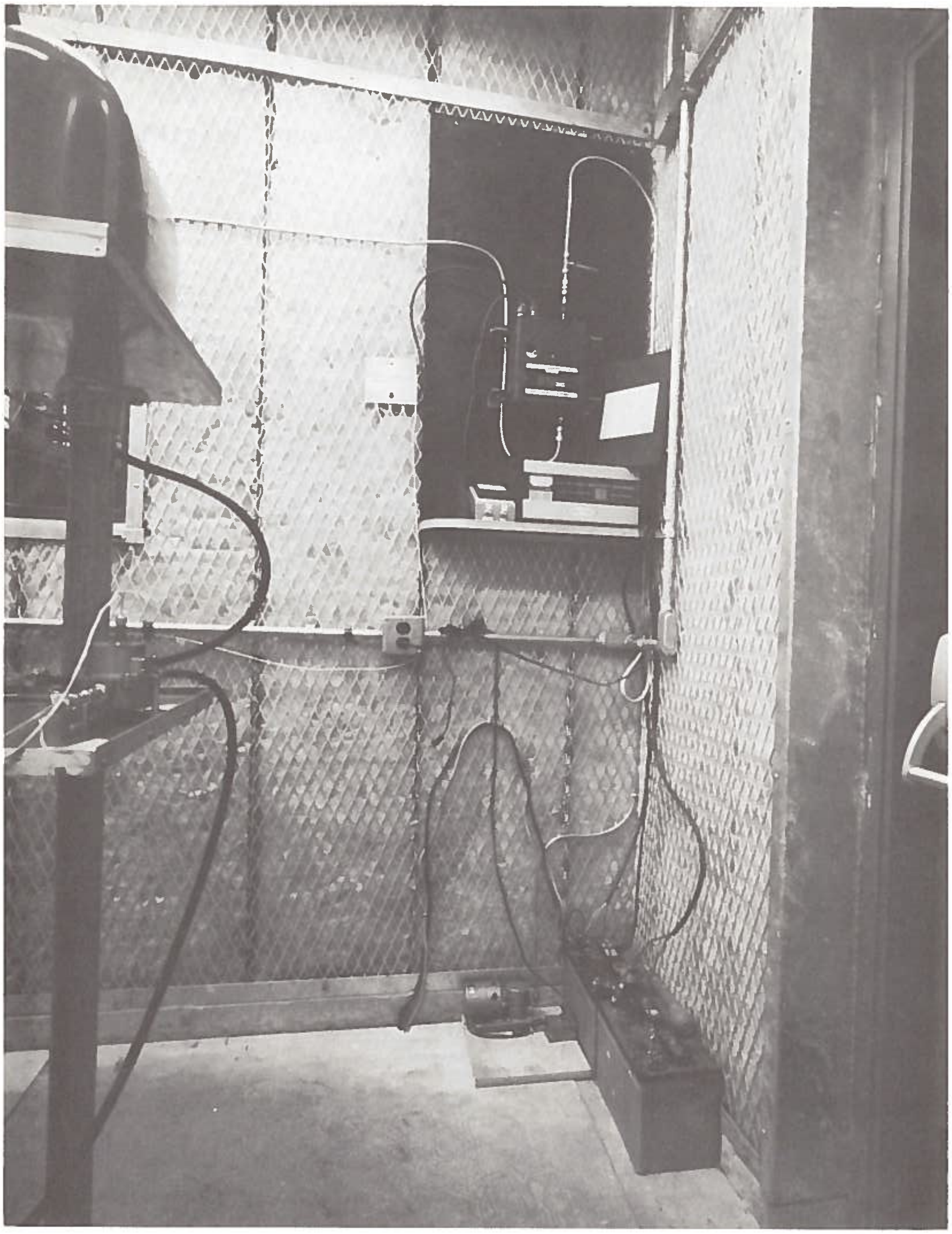

Figure 14. Carbon Monoxide Monitor Assembly and Power Supply

and the batteries are on the floor below. A switchbox adjacent to the charger connects the batteries in the series for powering the CO instrument, or in parallel for recharging overnight. Heavy cables from one of the batteries pass under the floorboards through a platen T-slot to the OM test-mount base, where they supply power to the OM electric-starting panel on the mount (visible in Figure 5).

4. CONTROL AND INSTRUMENTATION SYSTEMS

The control and instrumentation area is located outside the test cell in a fenced-in space adjacent to the east wall; this area is visible in the center of Figure 3. The control panel for the OM and dynamometer is the white structure adjacent to the fence at the southeast corner of the vestibule. It is south of the cell's east window, although in this view it seems to partially cover the window. The emissions-measurement instrumentation is installed in the large wheeled cart which, in Figure 3, stands just to the viewer's right of the control panel; it also is adjacent to the cell wall, about 2 feet north of the window. The following sections describe this area in detail.

4.1 ENGINE AND DYNAMOMETER CONTROL PANEL

Figure 15 shows the control panel on which are mounted most of the OM and dyno controls and instrumentation. The control operator's station is at the viewer's right end of the panel; from here he can see through the window into the cell. Attached to the viewer's right end of the horizontal "desk" surface or bench is the commercial remote control for the OM throttle; the control handle can be seen projecting above the bench top. Nearby, in the lower right corner of the aluminum mounting bracket, is the engine-stop switch; this permits the operator to short out the OM ignition primary and stop the engine quickly at any time. The engine-stop switch is wired in parallel with the ignition-cutout relay of the overspeed-safety tachometer system, which is positioned approximately in the center of the control panel.

The overspeed-safety tachometer is provided to prevent OM speed runaway and possible self-destruction in the event of a drive train break, loss of dyno load water, or operator error. The system directly monitors OM crankshaft speed (or the speed of some indispensably-linked component, such as the magneto/distributor unit of the OM shown in test in other figures of this report). In the two OM-test laboratories visited before this installation was

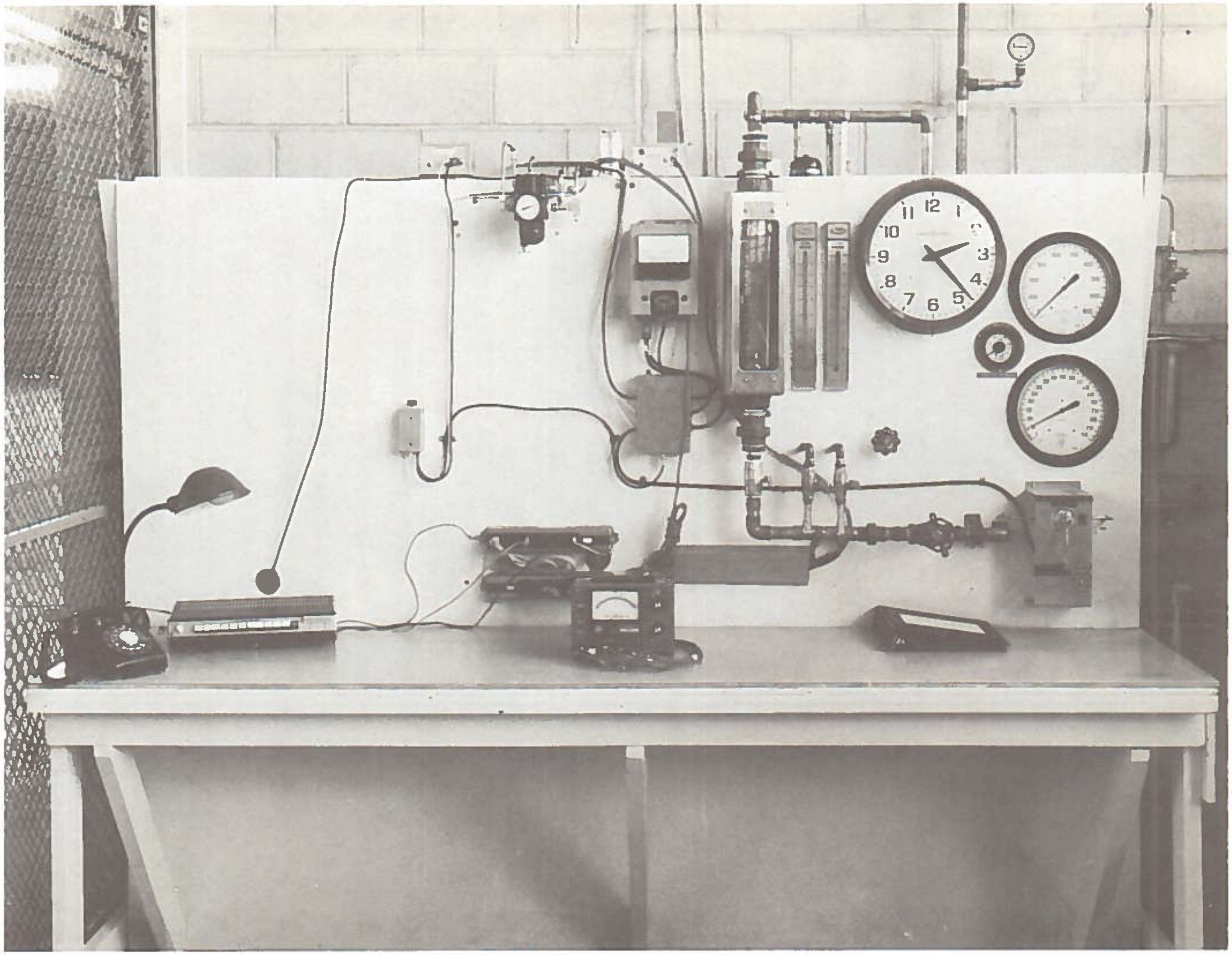

Figure 15. Outboard-Motor and Dynamometer Test Control Panel

designed, OM speed was sensed by detecting the passage of OM magneto magnets, or of alternator poles on OM's using automotive-type ignition systems; thus, different OM's required a variety of tachometer arrangements. Such a situation was highly undesirable for our program, in which the OM on the test mount would be changed almost weekly.

Accordingly, a hybrid tachometer system was chosen for our installation. An electro-optical sensing head was designed by project personnel to operate with a reflective chopper disc which could be used for all OM's tested. The sensing head then was mated by a manufacturer of magnetic-sensing tachometers to one of his standard monitoring and control units. (In fact, the capability of using the tachometer with magnetic sensing probes was retained.) The control unit is the box near the top center of the panel; the meter in this box displays OM speed up to 6000 rpm. If the speed signal is lost (because of sensor or signal-cable failure), fail-safe operation is provided by an underspeed-cutout features; OM speeds below about 300 rpm will cause ignition shutdown. Both the upper and the lower speed limits are adjustable.

Figure 16 shows the opto-electronic speed sensing head (which was visible in some of the earlier figures) and the reflective chopper disc installed on the magneto/distributor drive pulley. An infrared-emitting semiconductor diode (IRED) is attached to the finned aluminum "heat sink" which projects up to the right from the 45° pipe Y; IR radiation is projected down onto the chopper disc. This IR is reflected specularly by the bare aluminum segments of the disc up into the pipe leg screwed into the Y fitting, but the radiation is absorbed and diffused by the flat-black optical paint segments; the light; dark optical signal ratio is about 1600.1. IR entering the pipe leg passes through a visible-light-blocking filter to a collector lens which focuses it onto a phototransistor (detector). Electrical pulses passed by the transistor are conducted out of the test cell to the control unit. The steel-pipe construction of this head was chosen first to shield the detector from the possible influence of the rotating magnet in, and spark-ignition interference from, the OM, and second as a

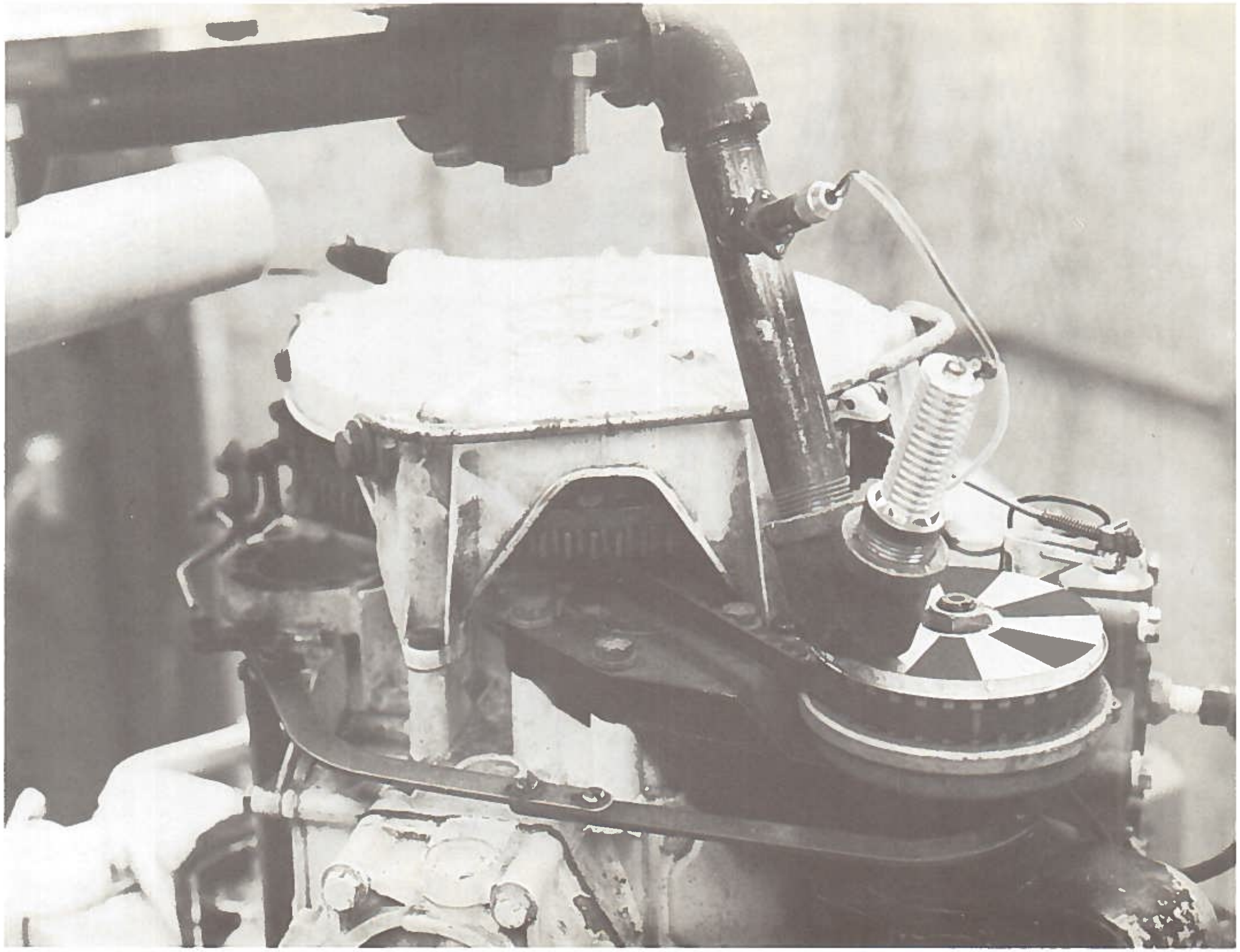

Figure 16. Opto-electronic Speed-Sensing Head for Overspeed Safety System

strong and rigid structural element. The chopper discs are fabricated from commercially-available reflective-label stock which is backed with pressure-sensitive adhesive; thus borrowed OM's will not be defaced.

The meter-equipped instrument seen in Figure 15 resting on the center of the bench top is a 12-channel thermistor thermometer. Cables from this instrument lead inside the test cell to monitor the temperatures of air and fuel entering the OM, OM power head cooling jacket and lower unit gearcase, tank water, both drive shaft pillow blocks, and the cooling/load water discharged from the dyno.

Load water for the dyno flows to the control panel from a pressure-regulating valve mounted atop the fuel-shortage room (this valve can be seen in Figure 3 just in front of the vent duct rising from the fuel storage room). The load-water pipe comes to the front of the panel adjacent to the aluminum bracket at the lower right of the panel, and leads left to the largest rotameter (variable-area flowmeter) adjacent to the overspeed tachometer. En route, the water encounters first the load-control valve, which can be seen in the pipeline directly below the clock, and two shutoff valves leading up to the two smaller rotameters adjacent to the clock. All three rotameters discharge in parallel into the load-water line leading back inside the cell to the dyno; any one of the three rotameters can be selected to measure load water flow rate, depending on the capacity required (1.0, 8.0, or 22.0 gpm), by opening the appropriate shutoff valve.

The two gages at the right end of the control panel indicate dyno torque in two ranges, 0-900 and 0-9000 in.-lb. They are connected to the one hydraulic load cell through the gage selector valve mounted at the top of the aluminum bracket positioned directly below the gages. Dyno shaft speed is indicated by the small circular tachometer mounted immediately adjacent to the gap between the two gages, on the left.

A digital readout may be obtained (with a counter not shown in Figure 15) of the signals from the fuel flowmeter, the overspeed tachometer (OM crankshaft speed), or the dyno tachometer. Selection of the desired signal, and output connection to the counter, are provided by the small switchbox mounted on the panel in the open area toward the left end.

4.2 EXHAUST-EMISSIONS MEASUREMENT SYSTEM

To the right of the control panel (as shown in Figure 3), on the north side of the window, is located the exhaust-emission measurement system. This instrumentation has been described previously in reference 3 and will be discussed in more detail in subsequent reports giving the results of this work.

The emissions from outboard and diesel engines are being measured on a real-time basis by an exhaust-analysis system contained in a caster-mounted cabinet (Figure 17). This instrumentation was assembled by Scott Research Laboratories to TSC specifications. The cabinet contains all the plumbing and fixtures necessary to assure proper handling and conditioning of the exhaust-gas sample. Figure 18 is a flow schematic of the system.

4.2.1 Instrumentation Description

The gas constituents being measured are carbon monoxide (CO), carbon dioxide (CO_2), nitrous oxide (NO), oxides of nitrogen (NO_x), oxygen (O_2), and total hydrocarbons (THC). The instruments used to measure these gases are briefly described below.

4.2.1.1 Non-Dispersive Infrared Analyzer for CO and CO_2 (MSA Model 202FR) - This instrument measures CO and CO_2 by their absorption in the infrared portion of the spectrum. The CO analyzer has four ranges: 0 to 0.05%, 0 to 0.2%, 0 to 2%, and 0 to 10%. The CO_2 analyzer has three ranges: 0 to 3%, 0 to 10% and 0 to 15%.

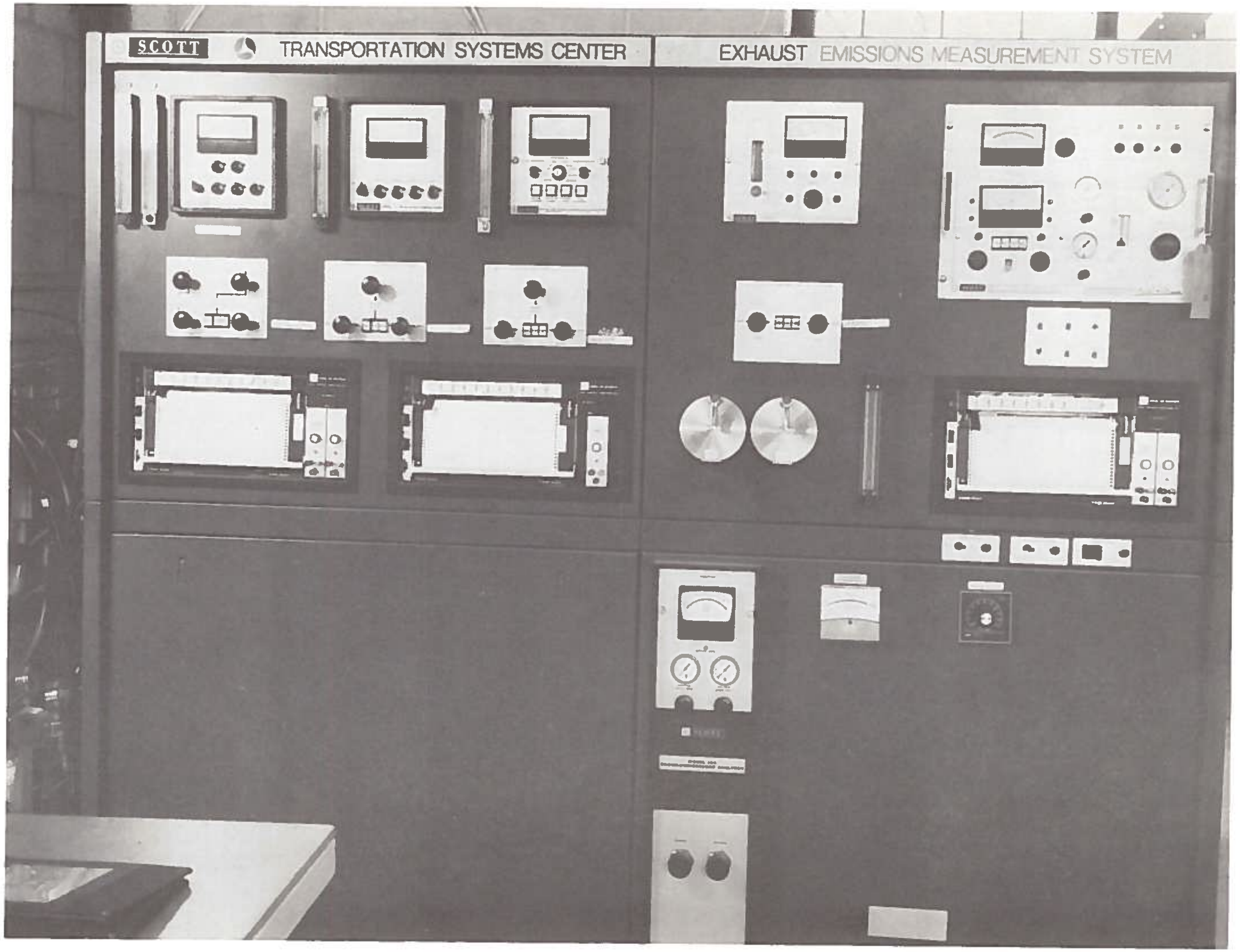

Figure 17. Engine-Exhaust Emissions Measurement System

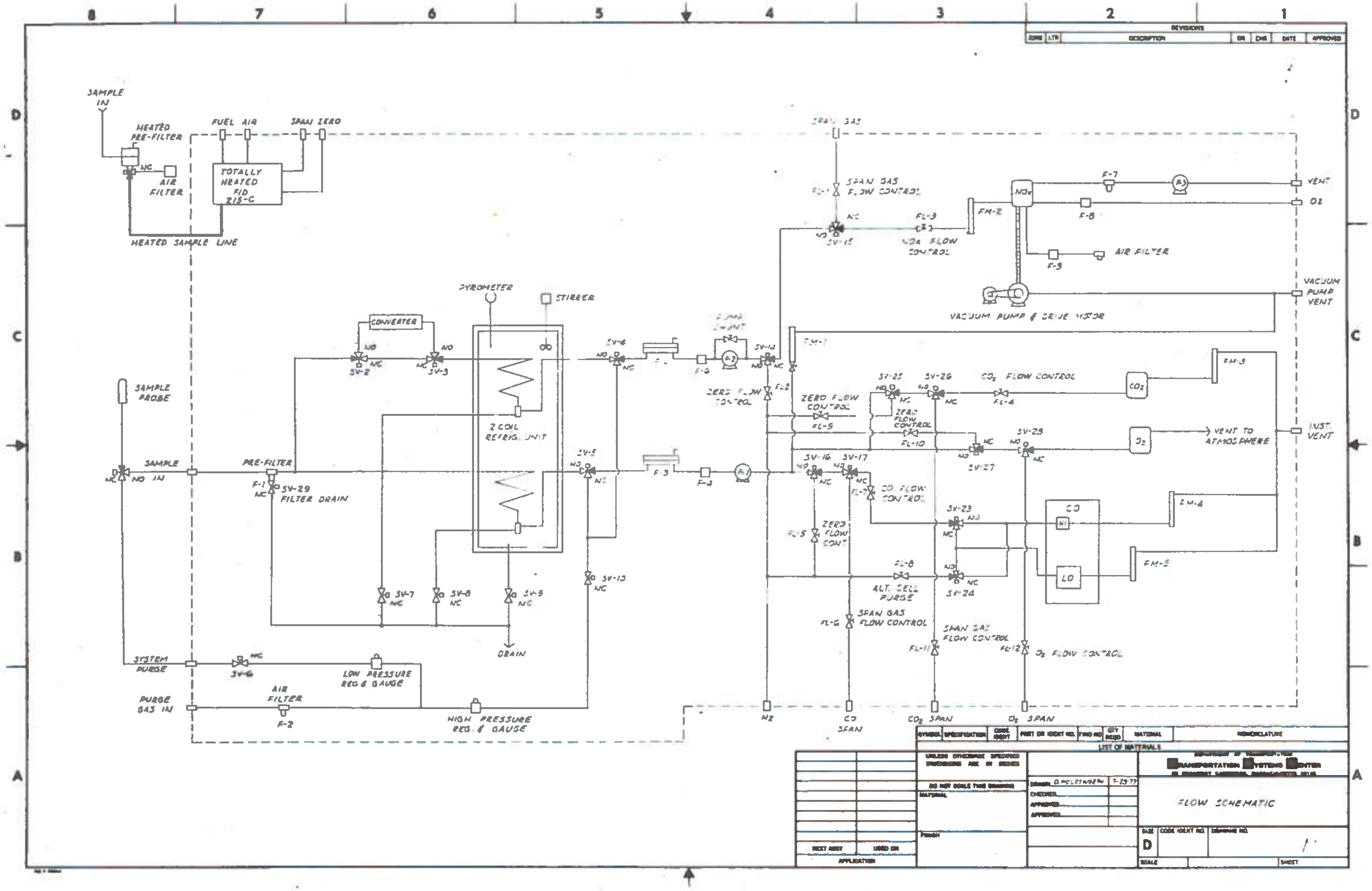

Figure 18. Flow Schematic for Emission-Measuring Instrumentation

4.2.1.2 Chemiluminescence Analyzer with Converter for NO and NO_x (Scott Model 125) - NO is measured by observing the light produced from the decoy of an excited state of NO_2 formed when NO reacts with ozone (O_3). NO_x is converted to NO in a heated converter for subsequent analysis and measurement by the chemiluminescence technique.

This instrument has seven switch-selectable ranges with full-scale readings from 2.5 to 10,000 ppm.

4.2.1.3 Paramagnetic Analyzer for O_2 (Scott Model 105) - Oxygen is a paramagnetic gas; when a laminar flow of gas containing O_2 is directed through a magnetic field, a pressure-sensitive detector measures the gradient developed across this gas stream and produces a signal proportional to the amount of O_2 in the stream. This instrument has four ranges: 0 to 1%, 0 to 5%, 0 to 10%, and 0 to 25%.

4.2.1.4 Flame-Ionization Detector (FID) For THC (Scott Model 215) - Total hydrocarbons are measured with a flame-ionization detector. Carbon atoms are "burned" in a clean hydrogen flame forming ions and free electrons. A fraction of these electrons produces a current proportional to the hydrocarbon atoms present. This instrument employs a totally heated sampling train to eliminate hydrocarbon condensation. The FID has eleven ranges from 1 ppm to 10 pph.

4.2.1.5 Data Recorders (Scott Model 200 Recorders) - Three strip-chart recorders produce a permenent record of the outputs of the instruments described in Sections 4.2.1.1 through 4.2.1.4. The recorders have ten switch selectable speeds from 3 in./hr to 360 in./hr.

4.2.2 Gas-Sample Handling and Conditioning

The gas sample for analysis is drawn from the exhaust manifold of the outboard engine above the point at which water is introduced into the exhaust. The sample is carried through twenty feet of sample lines for further conditioning at the instrument cart located outside the test cell.

4.2.2.1 Exhaust-Sampling Probe - To date, investigators of OM exhaust composition have sampled the exhaust by means of rigid probes inserted into the OM exhaust system above the point of which cooling water enters the exhaust system. This installation requires drilling and tapping holes into the OM. Such drastic and permanent alteration of borrowed OM's almost certainly would be unacceptable to the owners; replacing the damaged parts with new ones would be quite expensive, and for older engines new parts might be unavailable. We therefore made plans to use a flexible exhaust-sampling probe which could be inserted into the outer end of the OM's exhaust system and guided into the desired sampling position; this approach would require no machining of the OM's to be tested.

The design of such a probe posed several difficult problems, especially in terms of construction materials. During steady-state operation, the upper end of the probe will reach a temperature (from the cylinder) which is essentially that of the exhaust discharge. Typical full-load exhaust temperatures for OM's are not known; these two-cycle engines with overscavenging might reasonably be expected to have somewhat lower maximum temperatures than four-cycle automobile engines, which reach 1200-1400F. However, to avoid a malfunction, a minimum service temperature of 1400F was specified. The lower end of the probe, on the other hand, is in contact with the cooling water being discharged from the OM and also with the water in the lower unit tank. Thus the probe, which will be connected to a heated sample line maintained at a temperature of about 350F, requires some insulation--which must be both flexible and impervious to water, while also withstanding the erosive effects of pulsating high-velocity exhaust flow and temperatures up to 1400F and to some undefined distance down from the upper end. In addition, a minimal outside diameter of the probe, consistent with required gas flow, was desired to facilitate insertion through exhaust-discharge passages which are frequently long and rather narrow.

A probe which is believed to meet the above requirements reasonably well is shown in Figure 19, along with its two major component parts. The exhaust sample flows through a thin-walled stainless-steel tube which has been convoluted into a bellows configuration to provide flexibility; the bellows has nominal minor and major diameters of 0.25 and 0.38 inches, respectively. This sample conduit is isolated, if not really insulated, from ambient conditions by a similar outer bellows of stainless steel with nominal minor and major diameters of 0.40 and 0.60 inches, respecitvely; this fits coaxially over the sample tube. The probe tip, at the viewer's left in Figure 17 on the assembly at the top of the figure, is brazed to the end of the inner flexible tube, and the corresponding ends of the inner and outer tubes are sealed to each other by brazing to adapters. The inner bellows thus touches the outer bellows only at random points, with very limited surface areas in contact. The exhaust flow through the inner tube under steady-state conditions is expected to heat the inner tube to an acceptable temperature of at least 350F.

The discharge end of the probe has a minimum-feasible length of 1/4-inch diameter stainless tubing exposed for coupling to the next portion of heated line. This joint, which is out of the high-temperature exhaust region and continually splashed with water, will be insulated with fiberglass tape and sealed with shrink-fit electrical-insulation tubing. Heat from both the exhaust and the attached heated line should keep this joint at acceptable temperatures.

The assembled probe in Figure 19 has a convoluted portion considerably longer than the corresponding sections of the components shown below it, although the probe was made from identical components. It is possible to extend or compress the convoluted portions by reasonable amounts, and the probe elements were extended before assembly. (This probe had already been used in an OM and its exterior has been rather heavily fouled.)

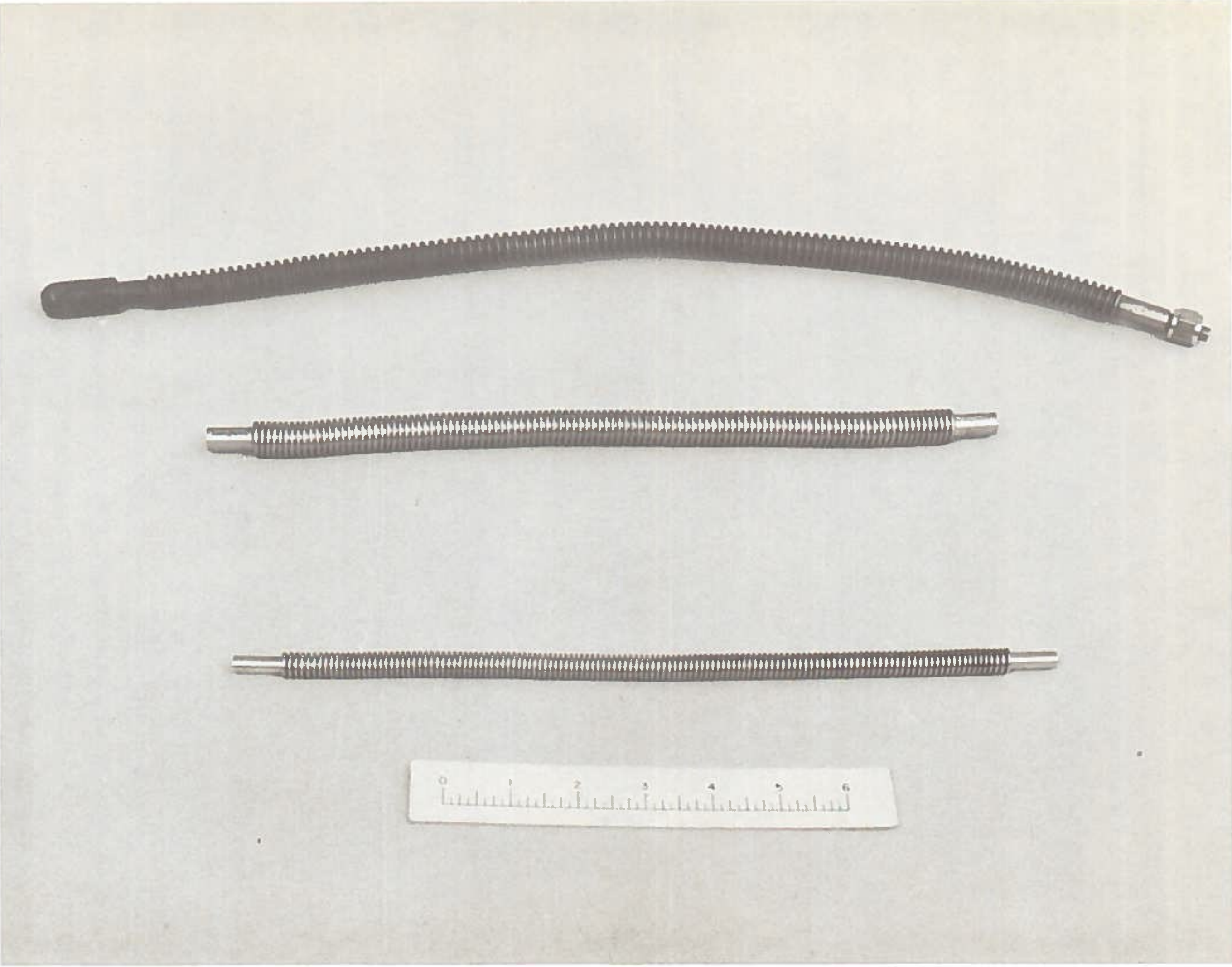

Figure 19. Flexible Coaxial Exhaust Sampling Probe With Major Components

The exhaust sample is drawn into the probe from gas passing along the sides of the tip, through four radial holes of 0.100 in. diameter. One of these holes can be seen in Figure 19 near the top of the probe tip, just slightly to the right of the curved nose of the tip.

4.2.2.2 Heated Sampling-Probe Extension - When the probe is installed in an OM such as the one shown in several earlier figures, the discharge end of the probe ends up at or near the outlet of the OM exhaust system in the lower unit. To conduct the sample gas from the probe to the outside of the lower-unit tank where it can enter the heated sample line of the emissions instrumentation, a probe extension which met many of the criteria for the probe itself was required. However, this extension clearly would have to be heated to maintain the gas temperature in the vicinity of 350F. It was decided to use a construction similar to that of the probe but of greater length. The extension is directly resistance-heated by passing low-voltage, high-current (up to 6.3 vac, 40 A) power through the coaxial tubes of the probe.

Figure 20 shows the heated probe extension in nearly-completed form; only attachment of electrical connectors and sealing of the ends of the outer jacket have not been done. The four Teflon-insulated wires leaving the hacket at the discharge end (lower center) run the full length of the jacket and are connected to the inlet end of the extension by a hose clamp visible inside the jacket at the upper left corner of the figure. The power connection to these wires is electrically grounded to the OM, since the uninsulated probe attached to the extension will be in contact with the metal of the OM. The discharge end of the probe will attach to a fitting which is electrically isolated from the test-mount assembly and connected to the 6.3 vac power lead. The outer flexible tube of the extension is wrapped with 8 layers of fiberglass tape as thermal insulation, and the entire length of the extension (except for end fittings) is jacketed with shrink-fit electrical-insulation tubing. The ends of the shrink-fit tubing are sealed to the extension metal jacket with silicone rubber.

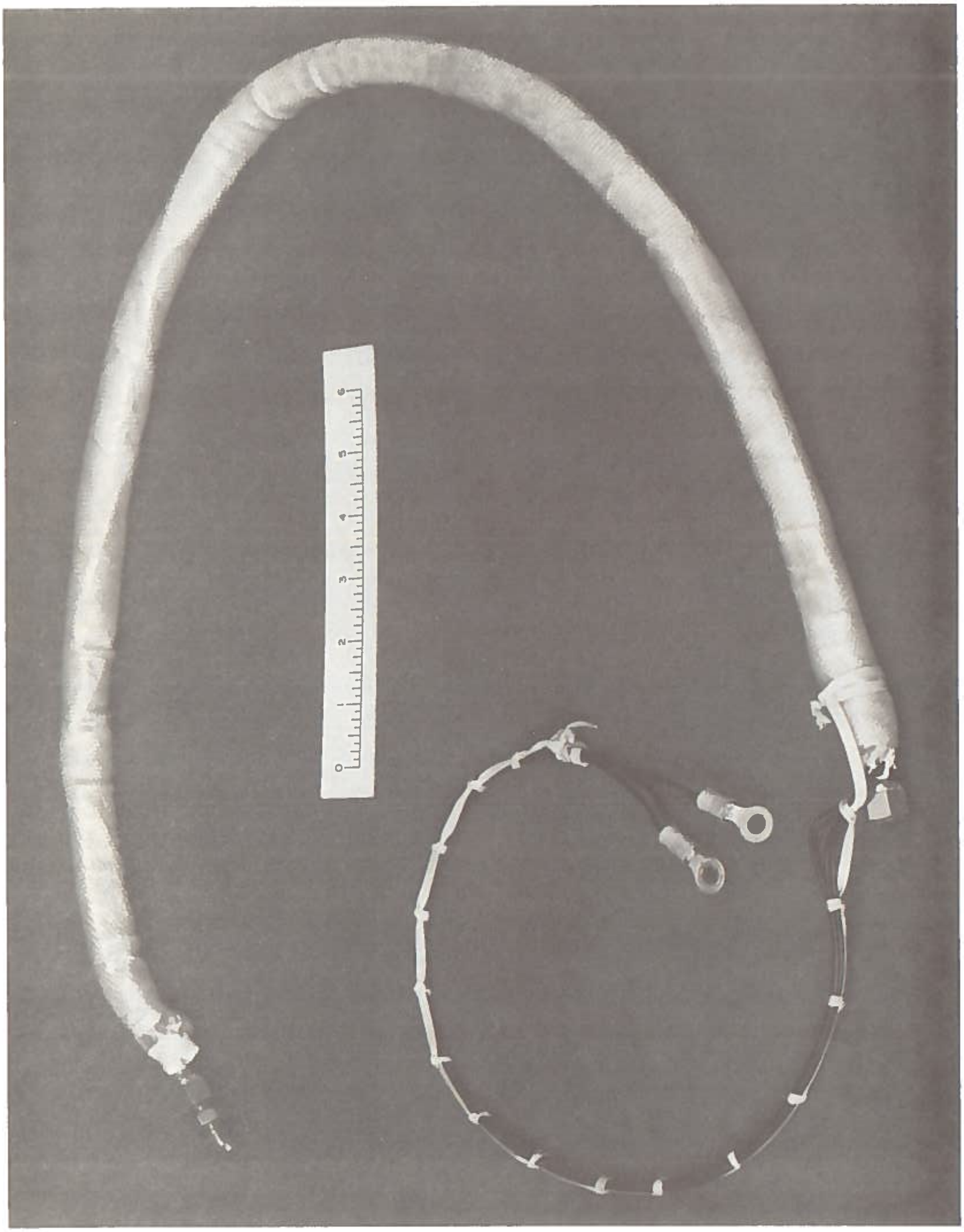

Figure 20. Heated Extension for Exhaust Sampling Probe

After assembly of the extension to the probe, the exposed joint will be wrapped with several layers of fiberglass tape and covered with shrink-fit tubing to exclude water.

Temperature of the heated extension is regulated by an automatic power controller which senses gas temperature leaving the extension and switches power to the step-down transformers on and off as needed.

It may have been noted, in Figures 7 and 8, that the probe extension was shown uninsulated. At the time those pictures were taken, the wiring and insulation had not been installed on the probe extension, and the extension was installed in its existing condition simply to illustrate the interior details of the lower-unit tank.

4.2.2.3 Sampling Lines - Outside the tank the sampling line is split into two lines, one heated and the other unheated. Both lines pass through the cell-wall sound-attenuation ports to the external instrumentation cart. The heated line with its heated pre-filter goes to the FID for measurement of total hydrocarbons. (This line is heated to 350F to 400F to eliminate hydrocarbon precipitation.) The unheated line carries the sample exhaust gas to all the other instruments.

4.2.2.4 Exhaust-Gas Sample Conditioning (Figure 18) - The heated sample line carries the exhaust gas directly to the FID for total hydrocarbon measurement. All elements of the FID that contact the gas stream are heated.

For the other instruments, the unheated line carries the gas sample to particulate filters and a refrigerated bath maintained at 32F for removal of condensables, especially water vapor, that could interfere with the measurement processes. Valves and flowmeters are provided to control the flow rates for the various instruments previously described (Section 4.2.1).

4.2.3 System Operation

The engine under test will be allowed to stabilize at the desired speed and load. All instruments will be zeroed and calibrated with the appropriate gases. The exhaust gas will then be sampled for the length of time necessary to assure that the operation and emission readings are stable. The instruments will then be zeroed and calibrated again and the sampling run repeated. The two runs will be compared for consistency.

As was previously mentioned, all emission data is recorded in real time on strip-chart recorders in parts per million (ppm) or percentages (pph) of exhaust-gas volume. All other important system and engine operating parameters will be recorded on data sheets. This data will be combined with the emission concentration data and entered into a computer. Computer programs have been developed for data storage and reduction of concentration data to mass-emission data (lb/hr, gm/bhp/hr, etc.) (Appendix) These programs will be refined as needed.

4.2.4 Exhaust/Water Contact System

Since the exhaust of an outboard engine is released below water level, an exhaust/water contact system has been designed to more closely simulate the actual conditions experienced by OM exhaust before it mixes with the atmosphere above the water.

The exhaust/water contact system is similar to that used by Southwest Research Institute (Reference 1); some changes have been made for easier operation. The system consists of a 12 in. OD x 24 in. high plexiglass bubbler tank and a similar level-control tank. The raw exhaust gas is bubbled through the tank water and sampled at the top of the tank. A pressure head and water-level control are maintained by a separate level-control tank. A 15-inch high plexiglass divider down the center of the bubbling tank will act as a weir and prevent recirculation of "contaminated" water.

The exhaust and water-flow rates are controlled so that the effects of the water/exhaust-gas ratio on the removal of exhaust-gas constituents can be studied. A propeller mounted at the bottom of the bubbler tank can be used to study the effects of water turbulence on the exhaust-gas water scrubbing process.

4.3 EVALUATION OF ENGINE PHYSICAL CONDITION

Tests made to assess the physical condition of the OM's surveyed will be limited to evaluations of the OM's ignition system performance and of the cylinder compression pressure or cylinder leakage at constant pressure. Whether any significant findings will result from these measurements is not known at present, and probably won't be until data have been accumulated for a number of OM's. At least one OM manufacturer has said that they don't make or recommend such tests, and cannot supply any criteria for interpretation of these data as they relate to engine wear or performance. However, the power output and presumably the combustion efficiency of internal-combustion engines generally are affected by compression pressure, and certainly two-stroke-cycle engines are notorious for being sensitive to ignition-system condition. Therefore it seems reasonable to expect changes in these parameters to influence OM emissions in somewhat the same way that they do automobile engine emissions--perhaps even more drastically.

Accordingly, when OM's are received for testing, compression on all cylinders will be checked before the OM is tested. When operation on the dyno stand is begun, ignition-system parameters will be measured under standardized speed and load conditions (in terms of per cent of maximums), and photographs of spark-voltage traces on an ignition oscilloscope will be taken. After the OM exhaust emissions have been measured in the "as-received" condition, the OM will be tuned by a factory-authorized dealer and all tests repeated. Probably little change will be seen in compression pressure (we do not plan to perform major over-hauls such as piston rings, crankcase seals, etc.), but noteworthy improvements in ignition voltages should be found in some OM's, especially in older ones with deteriorated ignition wiring (such wiring will be replaced when warranted). If compression pressure has any effect, it will probably be seen principally in the differing emissions of OM's which are about the same age but have significantly different compression readings, presumably as a result of varying degrees of wear.

Figure 21 shows one OM configured for ignition-system evaluation; the view is from the port side of the engine. The engine-performance test instrumentation can be seen in the background, on the starboard side of the drive train. In the foreground, attached to the starboard side of the drive train. In the foreground, attached to the spark plugs and resting on the rear edge of the power-head cover skirt, is an auxiliary distributor cap; this is a special accessory required for OM testing that is unnecessary for automotive analysis, and requires some explanation.

When engine-performance testing is done on ordinary four-stroke-cycle automotive engines, one test lead of the instrument is plugged into the high-voltage output terminal of the engine's ignition spark coil. This test lead is the one which is shown in Figure 21 plugged into the center socket of the auxiliary distributor cap; it has a white ceramic socket attached to the lead, and this socket is near the magneto/distributor of the OM. The high-voltage ignition wire leading to the auto engine's distributor, which normally plugs into the spark coil, now plugs into the ceramic socket on the test lead. This arrangement allows the test instrument to "sample" from a single point the spark voltage delivered to all plugs. Unfortunately, such an arrangement is not possible on many magneto-ignition multi-cylinder OM's, including the one on test in Figure 21.

OM's of this latter type generate the spark voltage in the magneto and deliver it to the distributor, which is part of the same assembly, by internal connections. For example, in Figure 21 the magneto/distributor is the black housing seen to the right of the power head under the belt-driven pulley; the magneto is in the upper part of the black housing, and the distributor is in the

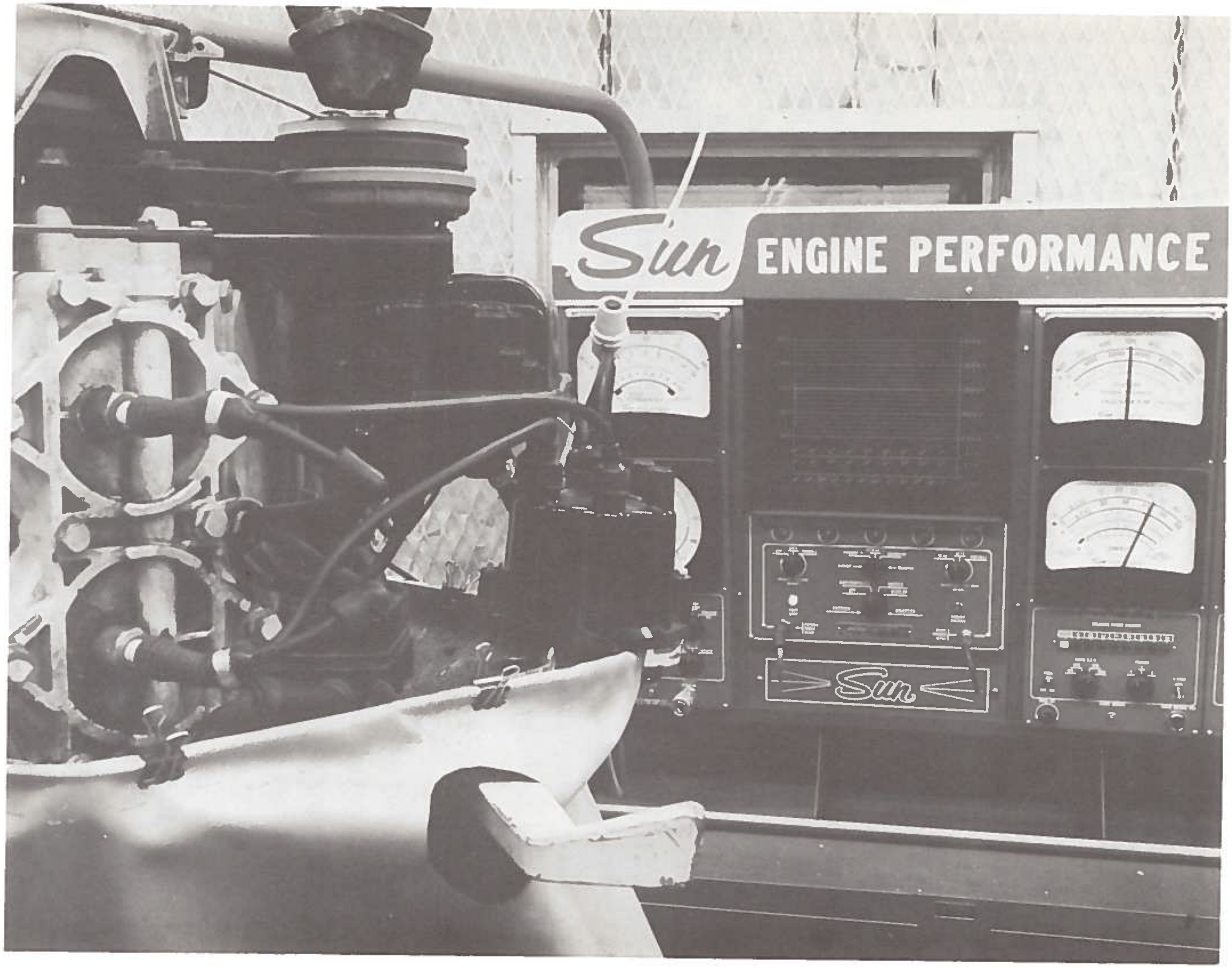

Figure 21. Outboard-Motor Ignition-System Evaluation Setup

lower part of the same assembly. The breaker-point housing is the shallow cup immediately beneath the pulley. The only exposed terminal is the "hot" side of the magneto primary, out of sight on the starboard side of the OM in this view; there is no external "high-tension" wire between coil and distributor, and hence no place to plug in the test instrument lead. Therefore the only access to the spark voltage delivered to the several plugs is at the spark leads going to the plugs; and, for different makes of OM's, the only common type of connection is at the cap of the plug itself (the lead usually connects to the distributor with a treaded terminal).

If sampling connections were made to all plugs and simply connected to a common point to which the test instrument lead could be attached, a spark pulse intended for any one of the several (OM's with 2, 3, 4, and 6 cylinders are expected to be tested) would instead by delivered in parallel to all plugs. This certainly would result in a very weak spark--if any--and very likely would cause engine malfunction, if combustion were initiated at all. Performance would surely be far from normal. The spark-sampling unit housed in the accessory distributor cap was built to preclude this problem.

Each lead of the spark-sampling unit has a short wire that plugs in between the spark-plub cap and the spark lead that normally connects to that cap. A longer lead connected to the short lead carries spark voltage to the sampling unit. There the voltage from any given lead passes through two 20,000-V silicon diodes connected in series to a common junction of the two-diode strings. Spark voltage entering through any one of the leads is prevented from passing out to any other of the leads (and hence to other spark plugs) by the blocking action of the reverse-biased diode strings in each of the other leads. The common junction of all leads provides a single point to which the test instrumentation lead can be connected to obtain a continuous sample of the spark voltages developed across all plugs.

A housing was needed in which to assemble and encapsulate the high-voltage diode network described and to provide well-supported connected terminals of a type suited for handling the 5,000-20,000-V spark voltages. A large distributor cap for a 6-cylinder automotive engine served the purpose admirably. After the diode network was soldered into the interior of the cap, the network was "potted" in a layer of silicone rubber to prevent arcing across the diodes and to protect operating personnel from accidental shock.

For an engine test, the required number of sampling leads for any given OM are plugged into the peripheral sockets of the sampling unit and connected in series with the spark leads to the individual plugs. The test instrument lead is plugged into the center socket of the sampling unit. The ceramic output socket of the test lead is not used in this operation, since the test connection is downstream of where this feature is required; this socket is merely left open. The other pertinent leads of the instrumentation are connected in normal fashion and the system is ready for test.

Ignition voltage signals may be displayed on the oscilloscope in several optional forms for various diagnostic purposes; those waveforms considered possibly useful for our purposes are photographed from the oscilloscope, printed in enlarged form, and saved for future comparison and evaluation. Particular attention will be paid to changes in ignition patterns which follow OM tuneup. Also, with those newer OM's which use automotive-type ignition coils, we will watch for reversed polarity of the coil--which can require up to 40 per cent more spark voltage to fire a plug than normal polarity does--and the effect of such connection on exhaust emissions. (It has been reported that ignition testing of one local dealer's stock of replacement coils showed that about 75 per cent of the coils had been marked with incorrect polarity. This situation was discovered quite by change while the test-equipment distributor was attempting to aid a user of his equipment in diagnosing a particularly difficult ignition problem in a customer's OM.)

5. FUEL STORAGE AND PREPARATION ROOM

Figure 22 shows a view into the fuel storage and preparation room. One 55-gallon drum of gasoline (the same controlled-formulation fuel used for emissions testing of new vehicles by U.S. auto manufacturers) at a time is stored in this room to allow it to reach ambient temperature. This gasoline is mixed with the appropriate quantity of two-cycle-OM lubricating oil in a 6.5-gallon plastic bottle, such as the one in the center of the figure, and then transferred to a standard 6-gallon portable OM fuel tank, one of which is shown on the platform of the scale. However, before any fuel is pumped out of the drum by the hand-operated rotary pump visible in the figure, fuel is first recirculated back into the drum long enough to ensure thorough mixing of the drum contents. The fuel mixing bottles have been calibrated to indicate the standard volumes of fuel mixtures normally prepared; both fuel bottles and fuel tanks are weighed before and after filling to ensure that correct gasoline/oil mixtures are obtained. All fuel tanks are stored in this room at the end of each working day.

A chain attached to a special holding fixture can be hooked to a loop on the door of this room to hold it open. If the CO_2 fire extinguishing system is actuated, the holding fixture will be pressurized by the CO_2 and will release the door. The door then will be closed by the spring-loaded door-closer, to contain the CO_2. Thus, in case of a fire, no personnel action is required to close this door. The inner door of the test cell is similarly equipped.

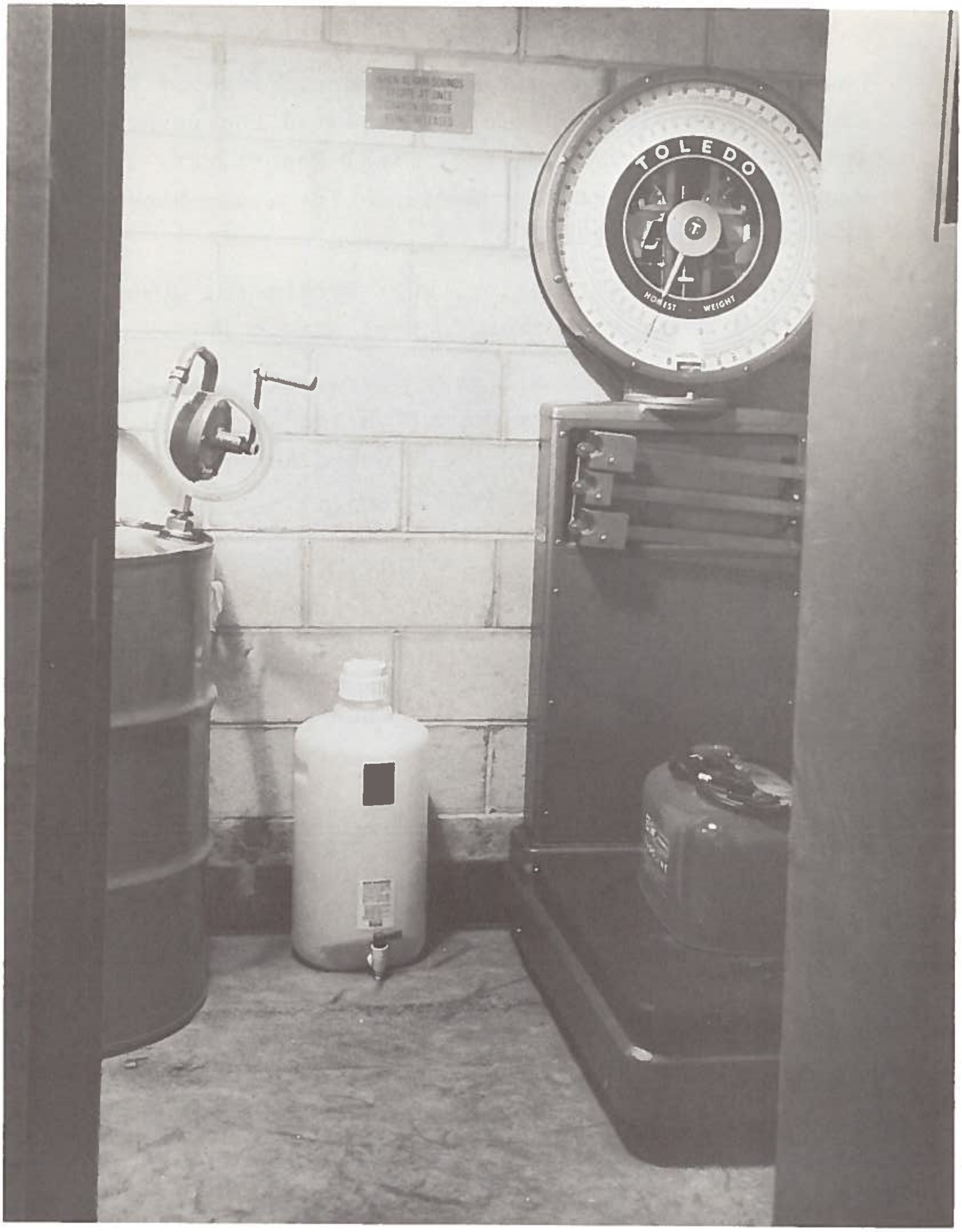

Figure 22. Fuel Storage and Preparation Room

6. REFERENCES

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2. 92nd Congress, 1st Session, U.S. Senate (S. 2096), "Outboard Motor Pollution Control Act of 1971."
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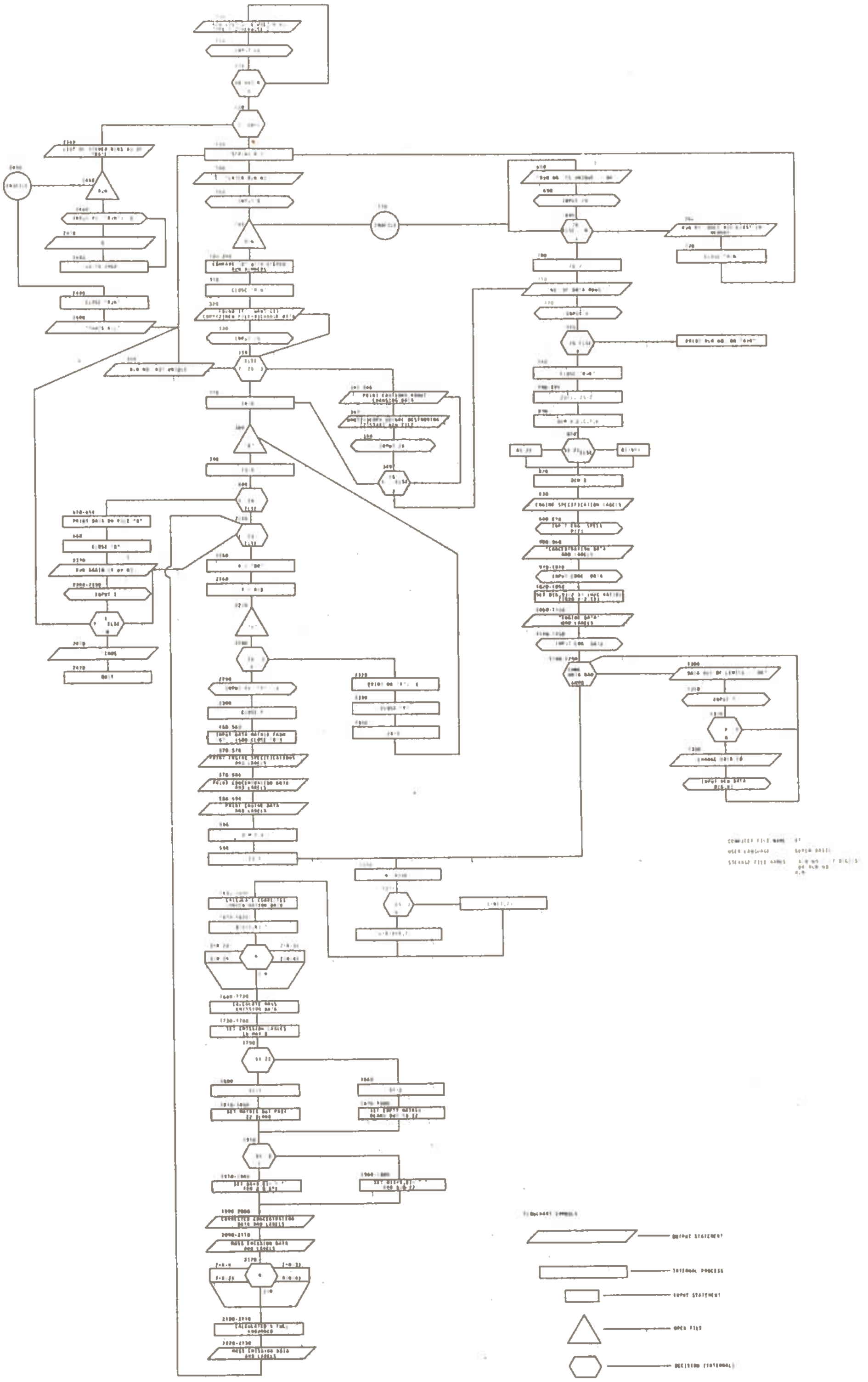
APPENDIX

OMES COMPUTER PROGRAM FLOW CHART


ENGINE SPECIFICATION LABELS
INPUT ENG. SPECS
ENGINE DATA AND LABELS
INPUT ENGINE DATA
INPUT I
PRINT ENGINE SPECIFICATIONS AND LABELS
PRINT ENGINE DATA AND LABELS
CALCULATE % FUEL
SET EMISSION LABELS
CORRECTED CONCENTRATIONS DATA AND LABELS
MASS EMISSION DATA AND LABELS
MASS EMISSION DATA AND LABELS
INPUT NEW DATA
COMPILED FILE NAME
USER LANGUAGE
STORAGE FILE NAMES
OUTPUT STATEMENT
INTERNAL PROCESS
INPUT STATEMENT
OPEN FILE
DECISION