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EXTINGUISHMENT OF ENGINE COMPARTMENT FIRES IN RECREATIONAL BOAT--ETC(U)
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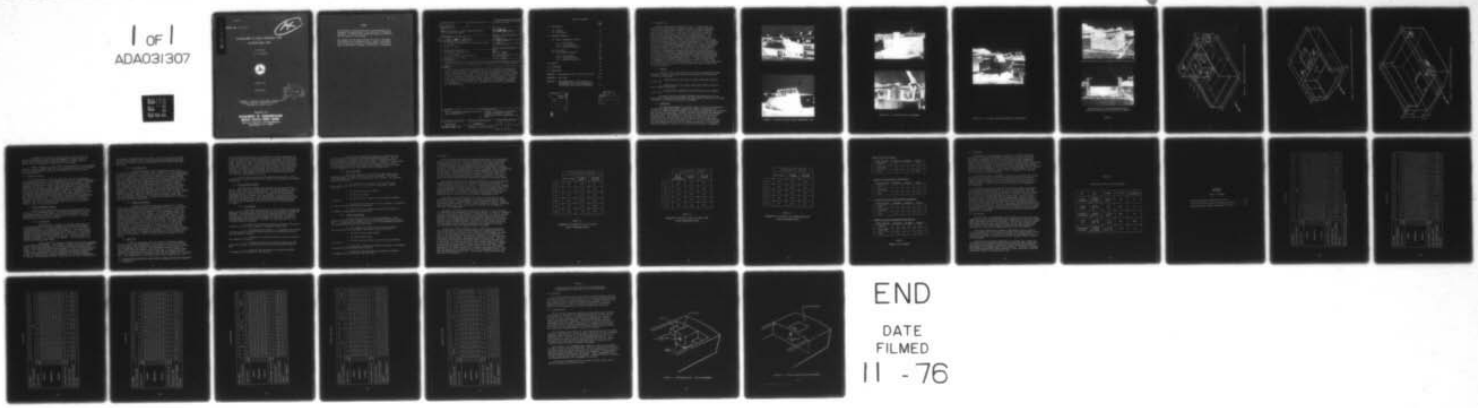

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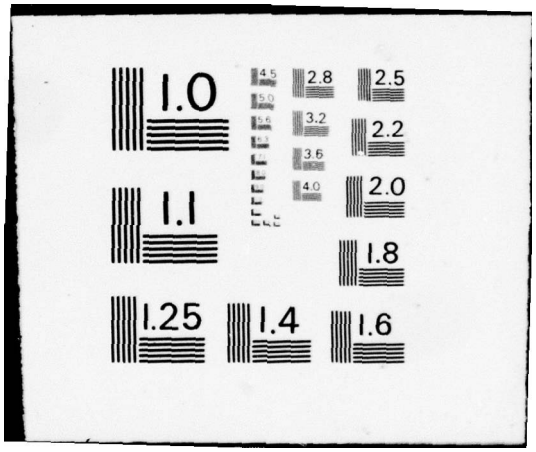
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Report No. CG-D-31-76

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EXTINGUISHMENT OF ENGINE COMPARTMENT FIRES IN RECREATIONAL BOATS

P. M. Dixon

R. C. Richards

January 1976

Final Report

Prepared for

DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD
Office of Research and Development
Washington, D.C. 20590

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16. Abstract

This report documents the evaluation of the "Port Method" of extinguishing engine compartment fires in recreational boats. In this method, the operator directs the extinguisher discharge into the engine compartment through a normally closed, but easily opened, port. The tests were conducted in full scale mockups of the aft sections of inboard/outdrive box type, inboard/outdrive across-the-stern, and the inboard flush hatch engine compartment configurations. Benefits of this method include confinement of heat and flame to the engine compartment, the limitation of oxygen to the fire, and greater effectiveness from handheld fire extinguishers.

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1.0 INTRODUCTION

Accident investigations analyzed by the U. S. Coast Guard over the past five years reveal a significant number of engine compartment fires in recreational boats. Figure 1 shows the results of typical engine compartment fires. These fires are usually fed by gasoline from the boat's fuel system. They are a serious threat to the boat operators and passengers because of their extreme intensity. The Coast Guard Research and Development Center therefore sought safer and more effective methods to control this type of fire without causing a significant expense to the boat owner or manufacturer. It was theorized that, if the engine compartment could be kept closed during extinguishment of such a fire, most of the heat would remain in the engine compartment thereby decreasing the heat exposure to the boat's occupants as well as limiting oxygen to the fire. This idea led to the development of a method of extinguishment in which a boat operator could attack such a fire with a portable fire extinguisher without endangering himself and his passengers. The method employs a normally closed, but easily opened, port in the wall of the engine compartment. A portable extinguisher can be directed and discharged through the port. It must be large enough to accommodate a portable extinguisher nozzle or horn but small enough to confine most of the heat and extinguishing agent to the engine compartment. For the purpose of this report the method described shall be referred to as the "port method."

1.1 Purpose

This test series evaluated the port method of extinguishing engine compartment fires in full-scale mockups of recreational boats having the following configurations:

a. Inboard/outdrive (I/O) box type engine compartment (Figures 2-A and 3-A).

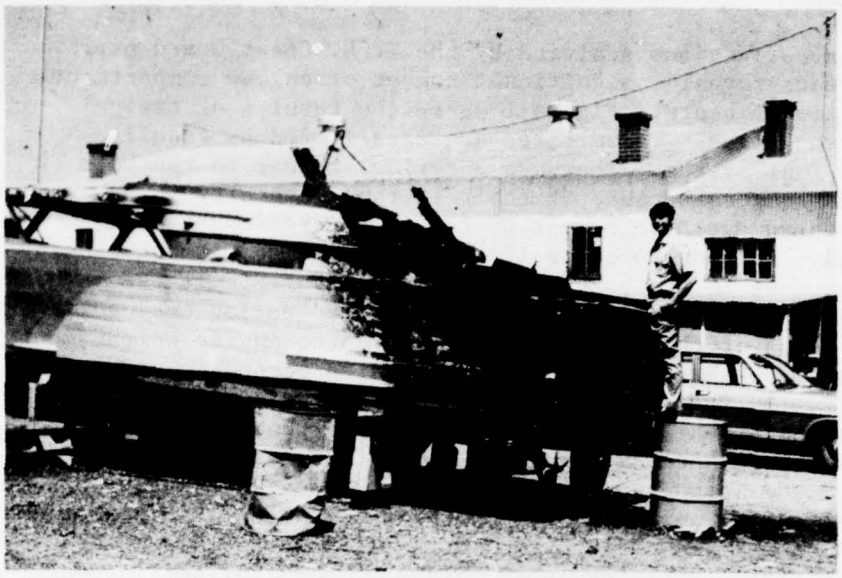
b. Inboard/outdrive (I/O) engine compartment located across the stern (Figures 2-B and 3-B).

c. Inboard engine compartment located beneath the deck (Figures 2-C and 3-C).

Secondary objectives include evaluating the effectiveness of the Coast Guard's extinguisher requirements for these types of boats and identifying unnecessary fire hazards which could be eliminated.

1.2 Limitations

The major disadvantage of full-scale tests is that all test parameters can seldom be duplicated without considerable expense of money and time. In this test series it was not possible to use all of the materials of construction that are used in a real boat. Plywood, insulated with asbestos and sheetmetal were used rather than fiberglass or wood that is usually used in this type of construction. Also deleted in the mockups were the many plastic and rubber parts used in small boats on motor mounts, wiring and other parts. In a real boat there is a much greater possibility of a fire which involves not only gasoline spills but also the combustible materials of construction. This would probably result in a fire that would be harder to extinguish.



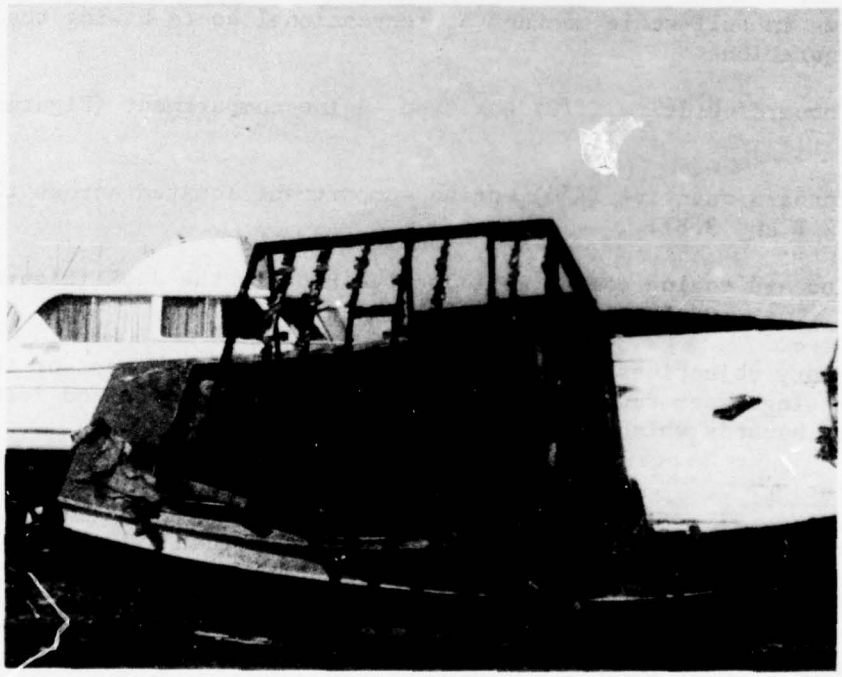


FIGURE 1. RESULTS OF TYPICAL ENGINE COMPARTMENT FIRES

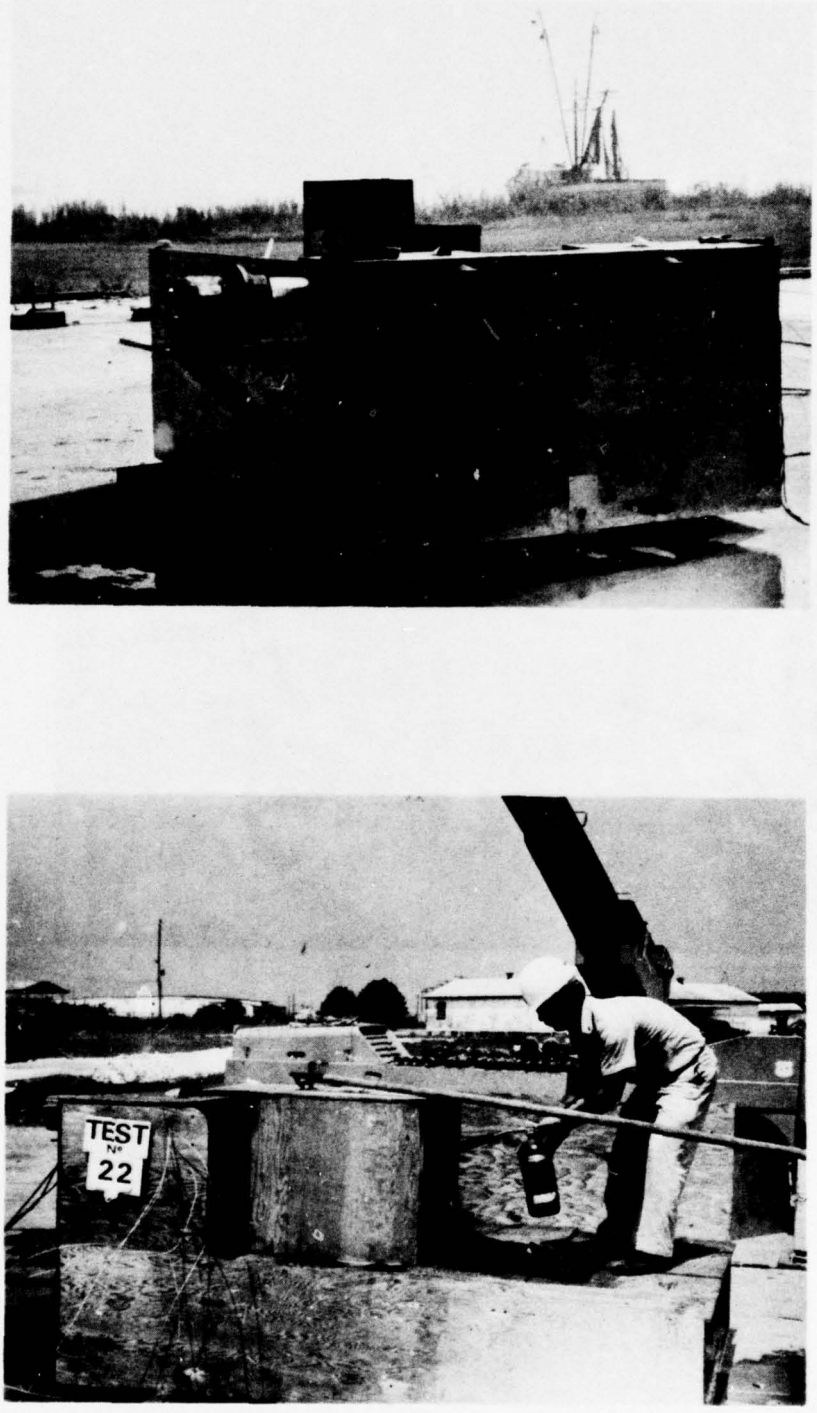


FIGURE 2-A. I/O BOX TYPE ENGINE COMPARTMENT

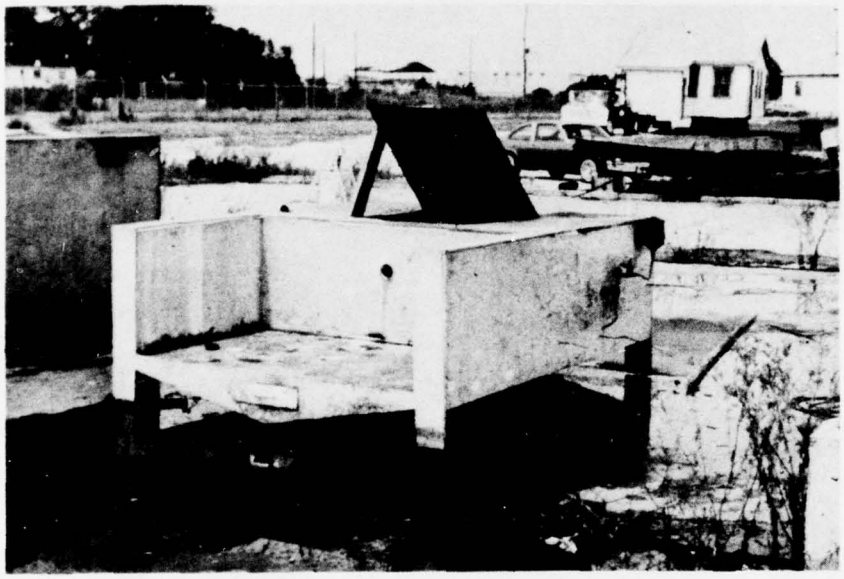
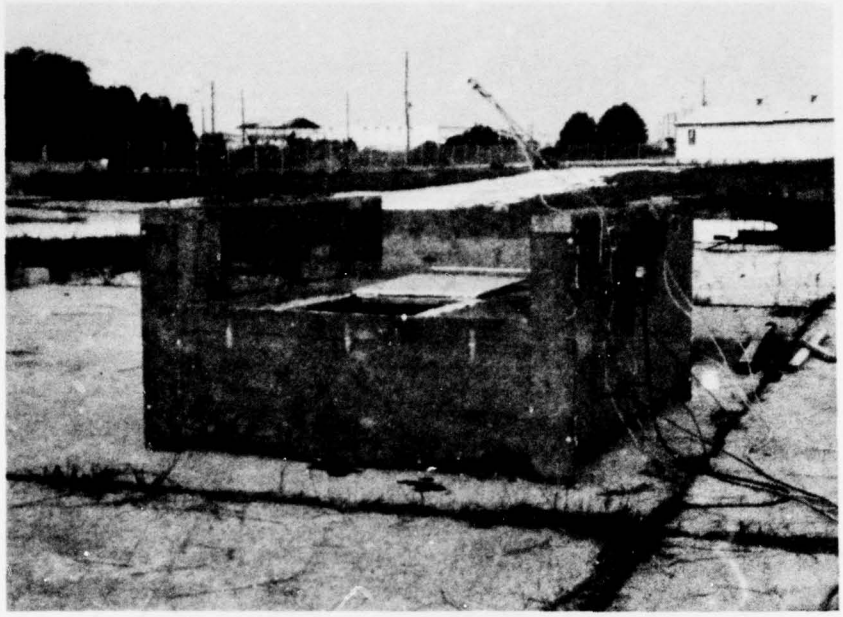
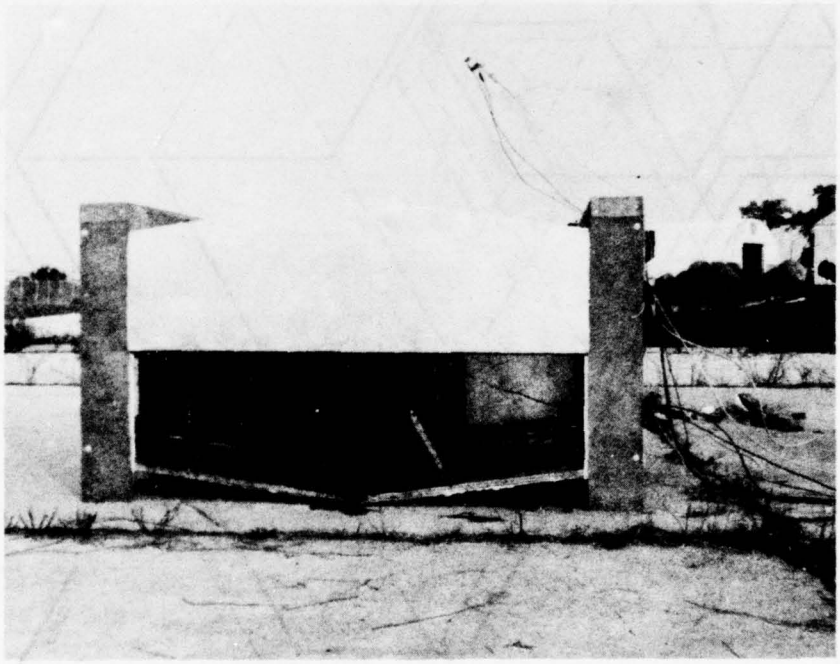


FIGURE 2-B. I/O ACROSS THE STERN MOCKUP WITH HATCH OPENED



INBOARD BELOW DECK ENGINE COMPARTMENT MOCKUP WITH HATCH OPEN



INBOARD BELOW DECK ENGINE COMPARTMENT MOCKUP
WITH ACCESS DOOR OPEN TO SHOW ENGINE AND BURN PAN

FIGURE 2-C

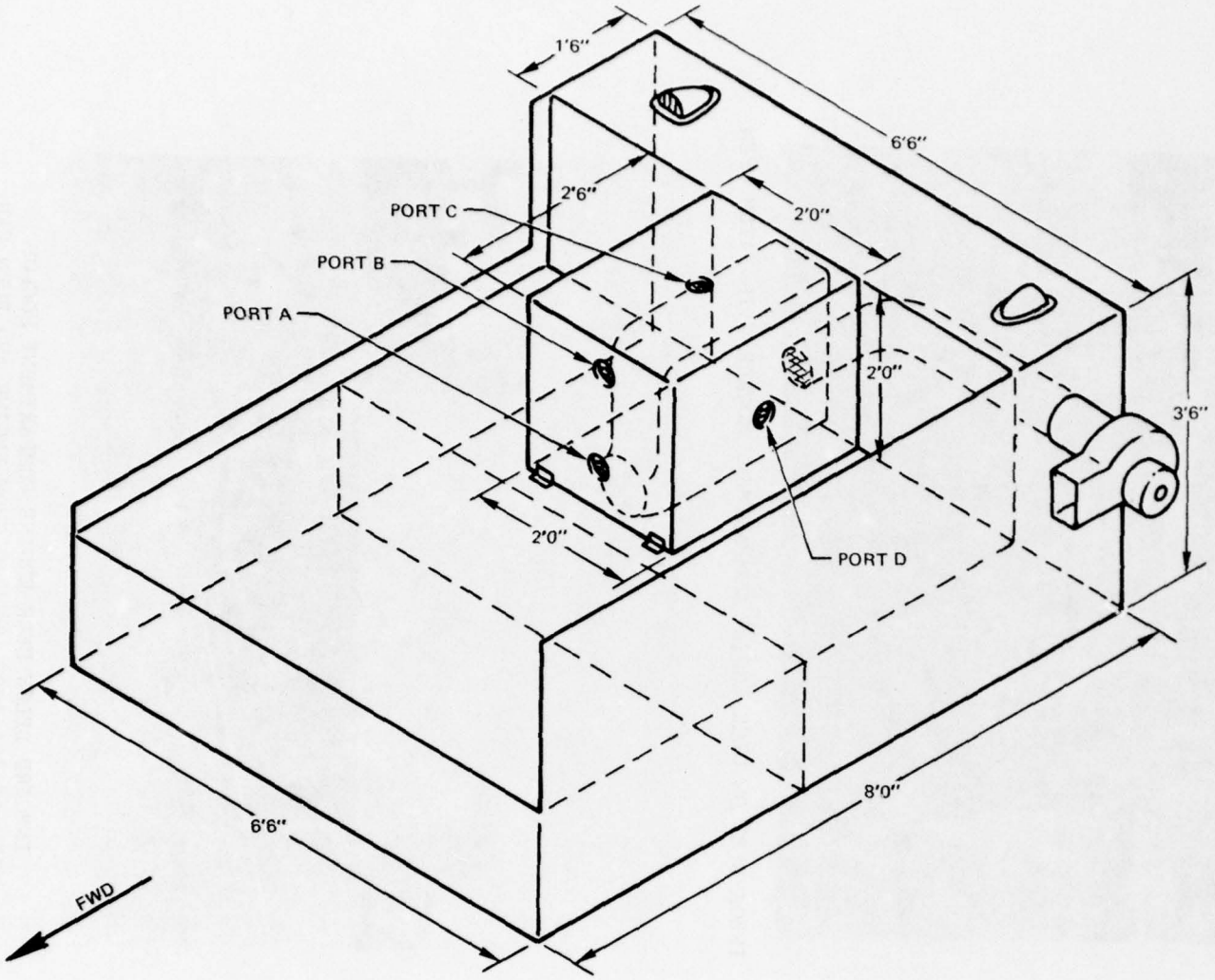


FIGURE 3-A. INBOARD/OUTDRIVE BOX TYPE ENGINE COMPARTMENT

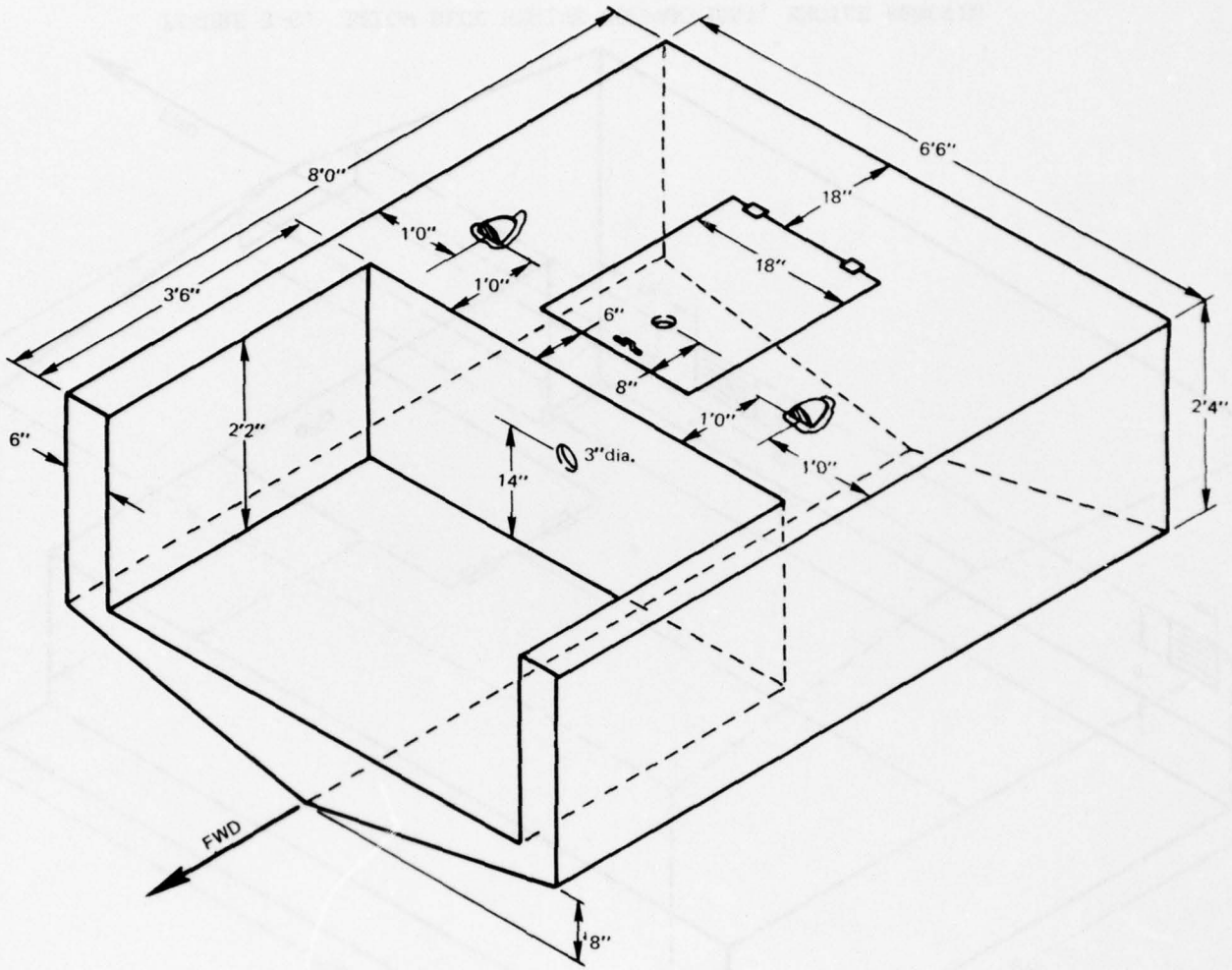


FIGURE 3-B. INBOARD/OUTDRIVE ACROSS THE STERN ENGINE COMPARTMENT, ENGINE REMOVED

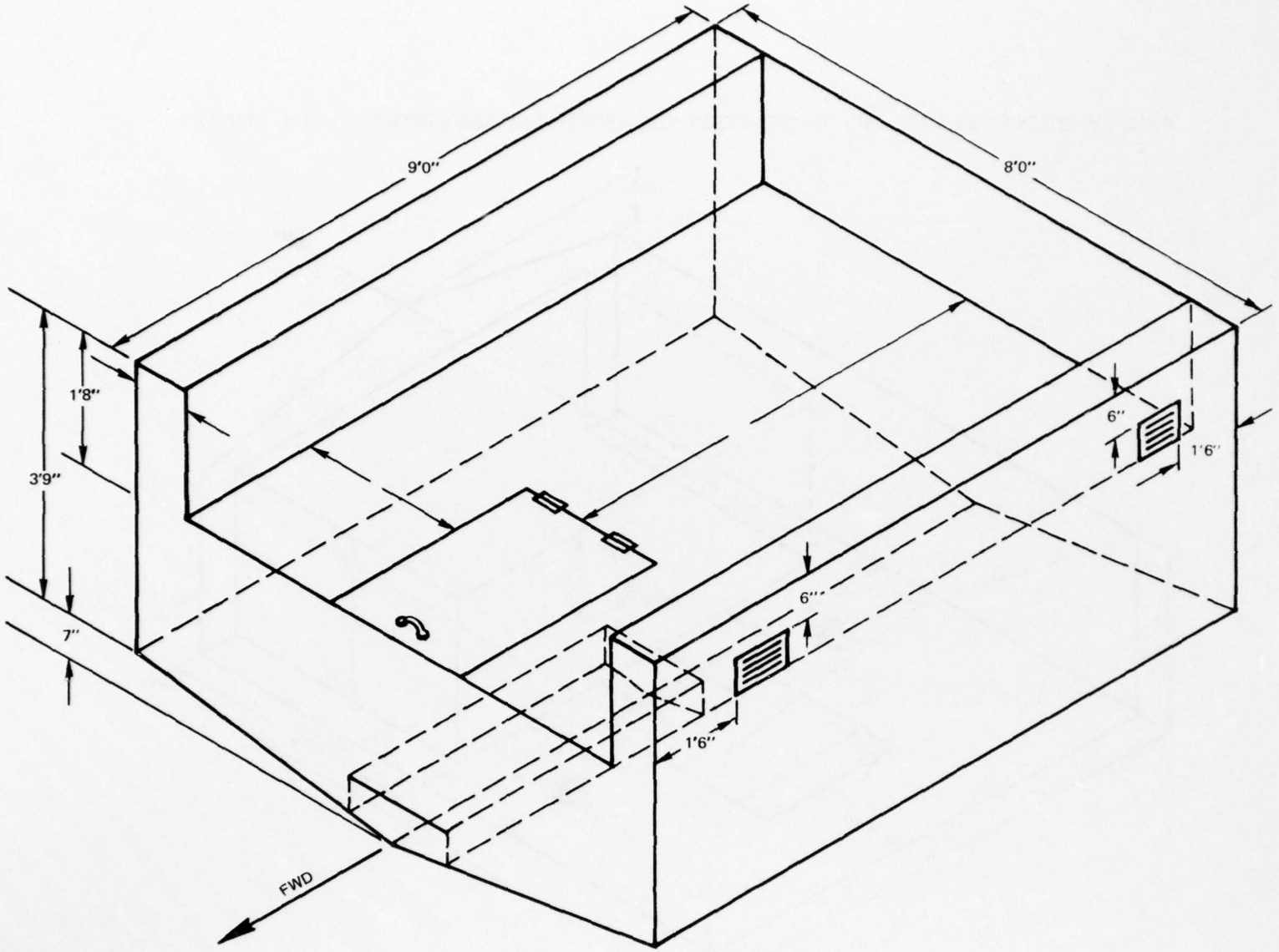


FIGURE 3-C. BELOW DECK ENGINE COMPARTMENT, ENGINE REMOVED

The design of the mockup is another limiting factor of the test. The designs were based on the average measurements of a wide variety of models. The mockups, therefore, were not identical in shape to any but were intended to be generally representative of most models.

Another limitation to these tests is the experience of the extinguisher operator. The test operator had been trained previously in the use of portable extinguishers and therefore would not be considered as a novice as would many boat operators.

2.0 COMPARISON TESTING

All of the parameters of an actual boat fire could not be reproduced in the mockups due to cost. Thus an evaluation of the port method by examining the actual characteristics of every possible fire was not possible. Therefore a method of comparison was chosen so that conditions would be similar and comparable for each test. The port method was compared to the conventional method of fully opening the engine compartment hatch to extinguish the fire. For the three boat configurations tested, a variety of extinguishers, all carrying the Coast Guard classification of B were used. This variety covered the commonly available gaseous and dry-powder fire extinguishers. They were chosen to determine if the results were a function of the extinguishing agent or extinguisher design. A particular extinguisher was defined as successful when the test fire was extinguished in at least 2 of 3 separate attempts. Each type of extinguisher was tested first on the open hatch fires and then by using the port method.

2.1 Engine Compartment Mockups

The three engine compartments used were full-scale models of the aft section of a recreational boat. The mockups were designed so that the extinguisher operator could attack the fire without having to leave the area to which he would normally be restricted in a real boat. A detailed description of each mockup is as follows:

2.1.1 I/O Box Type

The mockup used to simulate an inboard/outdrive box type engine compartment was designed to represent the aft end of an eighteen to twenty-foot boat. It was made of plywood with a 2" x 4" wood frame and was covered internally with sheetmetal for insulation. The mockup (shown in Figure 3-A) had an approximate volume of 107 cubic feet. A six cylinder internal combustion engine was installed over a six square foot metal pan between two stringers in the simulated bilge area. Fuel was stored in two reservoirs mounted on the outside of the transom. It was introduced into the burn pan through copper tubing.

During small boat operation the engine draws in large quantities of air through the carburetor. This creates a vacuum in the engine compartment which in turn draws replacement air in through the normal ventilating clam shells. This ventilation process would intensify a fire by providing additional oxygen to it. For this reason a duct simulating the carburetor was employed. It was located approximately where the carburetor intake would normally be and it provided for the continuous exhausting of the engine compartment at 350 cfm. The simulated carburetor intake was shut off before extinguishment

was attempted simulating engine shut down. This is the best (most logical and probable procedure) which could be followed when extinguishing a real boat fire. The mockup was also outfitted with the two required clam shell ventilators.

2.1.2 I/O Across Stern

The inboard/outdrive engine compartment located across the stern was simulated by the mockup shown in Figure 3-B. The mockup design[1] was largely influenced by a Century Mk II pleasure craft that was approximately 16 feet in length and 5'6" from gunwale to gunwale in the cockpit working area. An investigation of this configuration of engine compartment showed that most hatches had hinges toward the aft and thus opened from the forward direction. Examples of aft hinged forward opening hatches are found on other small boats with this configuration such as the Starcraft American S191.0, Wriedt Stinger 18 and Slick Craft SS-195. Accordingly, the mockup was equipped with a forward opening hatch. The mockup was constructed of plywood on a steel tubing frame and was insulated with asbestos paper and sheetmetal. It had a volume of approximately 95 cubic feet. An eight cylinder internal combustion engine was installed over a 6 square foot pan (18" x 48"). The fuel was introduced into the pan through copper tubing from a reservoir fastened to the transom. Ventilation was provided by 2 ventilating clam shells as shown in Figure 3-B.

2.1.3 Inboard Flush Hatch

Design of the inboard mockup was influenced by a 25-foot Trojan with a chine beam dimension of approximately 8 feet. A cross-section of boats examined indicated a range of beams from 7'6" to 8'0" with a few larger boats exceeding the 8'0" dimension. Hatch arrangements varied from single to split, with or without hinges. The 25-foot Trojan inboard, for instance, has two hatches. The lazzarette hatch, approximately 33" x 28" is completely removable and is equipped with lifting eyes. Deck to gunwale dimensions range from 20 to 30 inches in most models. Depth from deck to keel is approximately 32 inches in the models observed. A single, forward opening hatch was chosen with dimensions of 24" x 36". The fuel system and pan used in this mockup was the same one used in the I/O across the stern mockup. It was 18 inches wide, 48 inches long, and 3 inches deep. The mockup was constructed of plywood on a steel tubing frame and was lined with asbestos paper and sheetmetal for insulation. It had a volume of approximately 185 cubic feet. The mockup was provided with 4 louvers mounted in the hull for ventilation. Figure 3-C shows construction details for this mockup.

2.2 Test Fires

In order to assure that each fire was near its maximum possible intensity at the time extinguishment was attempted, pretests were conducted for each mockup. From observation of these pretests, a procedure for testing in each compartment was derived. These procedures varied in quantity of fuel, preburn time, and method of fuel distribution. Several pretests were conducted to determine if the quantity of fuel used was adequate to allow the fire to burn intensely for a period longer than that required for extinguishment. This assured that the fire did not go out due to lack of fuel. In

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[1] Mockups were modeled after existing boats representing average dimensions and arrangements.

the cover down test sequences, the possibility of self-extinguishment due to lack of ventilation in the mockup was also considered. To assure that oxygen starvation did not occur, each mockup was provided with ventilation ports. The size and shape of these ports was similar to those in use on common recreational boats. Pretest fires were then started in the mockups by the same procedure to be used in the actual testing. These fires were observed for a period of time exceeding that necessary for performance of the test. The mockups were then opened, and in all cases the fires were still burning. This confirmed that the limited oxygen starvation would not result in extinguishment of the fire.

All test fires were fueled with regular marine gasoline. Prior to fueling a few inches of water was put in the pan to provide a level surface for the fuel.

2.3 Fire Testing Procedures

The following procedures were employed in the testing of each mockup. Before each test, extinguishers were checked and weighed to assure that they were in proper working condition. All extinguishers used met the specifications of NFPA No. 10-1974, "Standard for the Installation, Maintenance and Use of Portable Fire Extinguishers," and all Coast Guard requirements for maintenance. After each test the extinguishers were again checked and weighed to assure that there had been no malfunctions during the test. The extinguishers used are listed by type and classification in Appendix A.

2.3.1 I/O Box Type

These tests included a total of four different extinguishing agents including Halon 1211, carbon dioxide, sodium bicarbonate, and ammonium phosphate. The extinguishers used were all Coast Guard Class BI except the Halon 1211 which carries no Coast Guard classification. The engine box contained port locations as shown in Figure 2-A. Each port location was tested separately in an attempt to determine the most effective one. The following method was employed:

a. Three to four ounces of naphtha was placed on the water's surface in the burn pan and ignited to establish a starter fire.

b. The engine box was closed; 5 oz. of gasoline was released into the starter fire and the blower simulating the carburetor air intake was simultaneously started.

c. Following a 30-second burn period, 20 ounces of gasoline was released into the fire.

d. Following a 60-second burn period the blower was shut off and the attempt to extinguish the fire by the method being tested was made.

e. After each test the mockup was cleaned and checked for damage before proceeding to the next test.

In the testing involving this mockup, an attempt was made to evaluate the effectiveness of different extinguishing agents. This was done by attempting to discharge only enough agent to extinguish the fire and then measuring the quantity which was not used. A measure of effectiveness was then made by comparison of the ounces of agent used per fire. After considering that the use of this method might be hampering the effectiveness of the extinguisher, it was discontinued in the remaining tests.

2.3.2 I/O Across Stern

These tests employed three different extinguishing agents including Halon 1211, carbon dioxide and sodium bicarbonate. The engine compartment (shown in Figure 1-B) contained one port location. The following test method was used:

a. The reservoir was filled with 28 ounces of regular marine gasoline and two ounces of fuel was added to the water's surface in the pan.

b. The fuel in the pan was ignited.

c. The hatch was closed.

d. The fuel valve was opened to add 28 ounces of gasoline to the fire.

e. Following a 25-second burn period the attempt to extinguish the fire by the method being tested was made.

f. After each test the mockup was cleaned and inspected for damages in preparation for the next test.

2.3.3 Inboard Flush Hatch

In these tests Halon 1211, potassium bicarbonate, carbon dioxide, and monoammonium phosphate were used as extinguishing agents through Port "A." Three tests were conducted using Port "B" and monoammonium phosphate. The following method was used for each test:

a. The reservoir was filled with 28 ounces of gasoline and two ounces of fuel was added to the water's surface in the pan.

b. The fuel in the pan was ignited.

c. The hatches were closed.

d. The fuel valve was opened to add 28 ounces of gasoline to the fire.

e. Following a 15-second burn period the attempt to extinguish the fire by the method being tested was made.

f. After each test the mockup was cleaned and inspected for damages before proceeding to the next test.

3.0 RESULTS

Visual observations included the aggressiveness used by the extinguisher operator in attacking the fire and the degree of difficulty in approaching and extinguishing the fire. It was noted that in the coverup tests, the extinguisher operator had considerable difficulty in approaching the fire. In all extinguishment attempts employing the conventional method of opening the hatch to attempt extinguishment the fire was so intense that the extinguisher operator could not have opened the hatch without dangerously being exposed to the flames. This made it necessary to use a boat hook or a rope to pull the hatch open before the fire could be attacked. The operator had very little difficulty in approaching the cover down fires except in the inboard mockup test where flames emitting from the port produced a noticeable hazard.

Measurements consisted of thermocouple readings, wind speed and direction, humidity, and ambient temperature. Thermocouple readings were taken at locations shown in Tables 1-A, 1-B and 1-C. Sixteenth inch, Type "K" chromel/alumel thermocouples were used in all tests. The maximum temperatures reached at each thermocouple position in each test are shown in Appendix B along with other test data. Thermocouple readings varied greatly during the tests. Temperatures often reached 750°F. The highest temperature recorded was 1306°F in Test No. 34 of the I/O box type engine compartment tests.

Wind speed and direction varied from 2 mph to 7 mph during the tests and wind direction shifted frequently, but neither had a noticeable effect on the test results. Relative humidity varied between 88% and 50%. Ambient temperature ranged from 26°C to 32°C. Neither humidity nor ambient temperature had a noticeable effect upon the intensity of the fire or the degree of difficulty in extinguishment.

Extinguisher malfunctions were reported in some of the tests involving the below-deck engine compartment in the inboard mockup. In order to extinguish a fire in this mockup it was necessary to hold the Halon 1211 and dry chemical extinguishers almost horizontally so that the agent could be directed into the port. These extinguishers were not designed to operate in this position and much of the extinguishing agent was left in the extinguisher after the pressure supply had been exhausted. This did not occur in tests involving CO_2 extinguishers because these extinguishers will completely discharge from any position due to the gaseous nature of the agent.

As the data in Table 2 indicates, only 8 of 108 separate extinguishment attempts failed. Three of these failures were experienced with the cover in the down positon while the port method of extinguishment was being tested. Of these three failures, one was attributed to a reflash due to wood burning in the mockup. The other two failures in the port method were noted in the inboard engine compartment located below the deck. These are attributed to the failure of the extinguishers to discharge properly due to the positon in which they were held. Five attempts failed to extinguish the fire with the hatch opened in the box type engine compartment. These failures were attributed to the limited access to the fire. The engine compartment cover hinges forward as it is opened, thus providing a barrier that the operator has to work around in order to extinguish the fire. This made extinguishment more difficult. More detailed information concerning each test is in Appendix B.

	DISTANCES FROM:		
	TOP OF STERN	AFT END OF MOCKUP	PORT SIDE OF MOCKUP
No. 1	2'6"	3'6"	3'3"
No. 2	3'	2'3"	3'3"
No. 3	1'2"	2'3"	3'3"
No. 4	2'0"	2'3"	2'9"
No. 5	2'0"	2'3"	3'10"
No. 6	2'6"	8"	3'3"

TABLE 1-A

THERMOCOUPLE LOCATIONS IN THE I/O BOX TYPE ENGINE COMPARTMENT MOCKUP

	DISTANCES FROM:		
	TOP OF ENGINE COMPARTMENT	AFT END OF MOCKUP	PORT SIDE OF MOCKUP
No. 1	2'6"	2'0"	3'3"
No. 2	1'0"	3'0"	2'0"
No. 3	1'0"	3'6"	4'6"
No. 4	1'0"	1'0"	2'0"
No. 5	1'0"	1'0"	4'6"

TABLE 1-B

THERMOCOUPLE LOCATIONS IN THE I/O ACROSS STERN ENGINE COMPARTMENT MOCKUP

	DISTANCES FROM:		
	DECK LEVEL	AFT END OF MOCKUP	PORT SIDE OF MOCKUP
No. 1	2'5"	7'0"	4'0"
No. 2	1'0"	8'0"	2'0"
No. 3	1'0"	8'0"	2'0"
No. 4	1'0"	6'0"	2'0"
No. 5	1'0"	6'0"	6'0"

TABLE 1-C

THERMOCOUPLE LOCATIONS IN THE INBOARD BELOW DECK ENGINE COMPARTMENT MOCKUP

TOTALS OF ALL TEST RESULTS

COVER POSITION	SUCCESSES	FAILURES	TOTALS
COVER UP	31	5	36
COVER DOWN	69	3	72
TOTAL	100	8	108

1. I/O BOX TYPE CONFIGURATION TEST RESULTS

COVER POSITION	SUCCESSES	FAILURES	TOTALS
COVER UP	7	5	12
COVER DOWN	47	1	48
TOTAL	54	6	60

2. I/O ACROSS THE STERN CONFIGURATION TEST RESULTS

COVER POSITION	SUCCESSES	FAILURES	TOTALS
COVER UP	9	0	9
COVER DOWN	9	0	9
TOTAL	18	0	18

3. INBOARD BELOW DECK CONFIGURATION TEST RESULTS

COVER POSITION	SUCCESSES	FAILURES	TOTALS
COVER UP	15	0	15
COVER DOWN	13	2	15
TOTAL	28	2	30

TABLE 2

SUMMARY OF TEST RESULTS

4.0 DISCUSSION

The results of these tests show that there is a definite advantage in the use of the port extinguishment technique for fires in the I/O box type engine compartment and the I/O across the stern engine compartment. In these two configurations, fire can be approached by the extinguisher operator without the unnecessary exposure to heat and flame that is experienced when the hatch is opened. The port extinguishment technique also provided a method of extinguishment in which most of the extinguishing media is retained inside the engine compartment. This proved to be an advantage. The fact that little or no training is needed to safely extinguish a fire by using the port method is another advantage.

In the box type engine compartment, several port locations were tested. In all port locations the tests were successful, but Port B (as shown in Figure 2-A) was determined to be the best alternative since it is in an easily accessible location and it can be used with the extinguisher in the upright position. Appendix C gives detailed information on recommended port locations.

The results of the tests involving the below deck engine compartment did not show the advantages seen in the other configurations. For both port locations tested the amount of exposure to heat and flames was reduced but flames would still blow through the port in the deck. This proved to be a hazard to the extinguisher operator since he had to be very close to the port in order to effectively use the extinguisher. Another problem encountered while using the port method in this configuration was that the Halon 1211 and the dry chemical extinguishers had to be held horizontally in order to direct them into the port. This caused extinguisher malfunctions as discussed in Section 3.0. Even with these hindrances, 13 out of 15 tests were successful, but similar results could not be expected with an untrained boat operator in an actual fire situation where protective clothing would probably not be available.

5.0 CONCLUSIONS

The port method of extinguishment was successful in the box type engine compartment and the across-the-stern engine compartment but not in the inboard engine compartment located below the deck. In all tests in which the engine compartment hatch was open it was noted that the fire was so intense that the operator could not have opened the hatch with his bare hands without being exposed to the heat and flames emitted from the hatch opening.

These tests indicate that a number of improvements could be made in most boat designs that would result in increased fire safety without costing a great deal of money. A port could be located at a convenient spot in the engine compartment and labeled so that boat operators would be familiar with its purpose.

For the below deck engine compartment it is evident that neither the port method nor the conventional method of attacking an engine compartment fire is entirely sufficient. However, with some redesign and/or special arrangements, the technique would be made effective. Otherwise, it appears that a fixed extinguishing system installed in these models may be the only satisfactory method of attacking such a fire.

APPENDIX A

EXTINGUISHERS USED IN FIRE TEST SERIES

TYPE	MODEL	CONTENTS	UL RATING	USCG CLASSIFICATION
SODIUM BICARBONATE	AMERICAN LAFRANCE MOD. 275R-5C	2 3/4 lb. $NaHCO_3$	5:BC	BI
CARBON DIOXIDE	GENERAL MOD. 5-R	5 lb. CO_2	5B:C	BI
POTTASIUM BICARBONATE	GENERAL MOD.KCP-2 1/2	2 3/8 lb. $KHCO_3$	10B:C	BI
HALON 1211	GRAVINER MOD. 210	2 lb. C BrCLF	2BC	NONE
MONOAMMONIUM PHOSPHATE	AMERICAN LAFRANCE MOD. 250A-C	2 1/4 lb. $NH_4\ H_2\ PO_4$	5:BC	BI

APPENDIX B
TEST DATA

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I/O BOX TYPE

TEST NUMBER		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
TYPE OF EXTINGUISHER		$NaHCO_3$														
COVER POSITION	UP	✓	✓	✓												
	DOWN				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
MAXIMUM THERMOCOUPLE READINGS	1	469	273	402	160	76	96	473	407	291	590	392	285	589	74	225
	2	351	437	201	363	70	177	918	296	179	617	204	193	614	76	205
	3	322	382	199	284	210	167	344	222	136	404	199	146	415	220	232
	4	87	174	120	177	153	117	143	136	110	138	106	119	176	102	139
	5	114	329	134	158	147	122	152	123	122	161	105	133	108	83	134
	6	142	488	419	339	423	371	212	403	208	112	374	228	115	331	398
EXTINGUISHMENT SUCCESS	YES				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	NO	✓	✓	✓												
WIND VELOCITY (MPH)		4	4	3	3	3	4	4	3	3	3	3	3	4	3	3
*WIND DIRECTION (DEGREES)		0	30	110	20	90	90	0	90	90	30	30	140	0	0	120
PORT USED		-	-	-	A	A	A	B	B	B	C	C	C	D	D	D

*Wind Direction is measured in degrees relative to the mockup with the forward end representing zero degrees.

I/O BOX TYPE

TEST NUMBER		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
TYPE OF EXTINGUISHER		CO_2														
COVER POSITION	UP	✓	✓	✓												
	DOWN				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
MAXIMUM THERMOCOUPLE READINGS	1	582	134	117	583	82	90	576	326	68	581	95	319	82	78	38
	2	737	221	249	342	224	71	593	224	127	660	128	343	80	107	197
	3	272	133	239	168	234	181	400	238	135	259	109	112	233	153	134
	4	100	85	119	92	118	117	134	103	110	162	130	96	164	113	136
	5	91	86	140	104	138	116	143	118	121	114	122	122	151	103	141
	6	84	304	220	77	368	396	155	380	220	98	348	277	421	391	315
EXTINGUISHMENT SUCCESS	YES	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	NO															
WIND VELOCITY (MPH)		4	3	3	4	4	3	4	3	3	3	3	2	4	3	4
WIND DIRECTION (DEGREES)		30	60	110	130	140	7	30	60	150	180	90	90	190	6	160
PORT USED		-	-	-	A	A	A	B	B	B	C	C	C	D	D	D

I/O BOX TYPE

TEST NUMBER		31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
TYPE OF EXTINGUISHER		ABC														
COVER POSITION	UP	✓	✓	✓												
	DOWN				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
MAXIMUM THERMOCOUPLE READINGS	1	448	326	324	618	209	95	468	200	330	419	280	40	534	302	200
	2	421	270	222	708	158	155	349	225	262	363	254	190	533	366	394
	3	299	139	110	338	227	254	195	267	196	226	180	131	287	183	749
	4	173	111	128	111	97	122	98	122	129	168	152	128	197	149	112
	5	162	122	130	99	111	190	192	123	133	208	129	135	142	145	172
	6	186	426	305	88	352	237	103	367	350	387	451	300	187	496	339
EXTINGUISHMENT SUCCESS	YES		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
	NO										✓					
WIND VELOCITY (MPH)		3	3	4	4	3	4	4	3	4	3	4	4	4	3	2
WIND DIRECTION (DEGREES)		60	60	90	30	60	90	0	190	80	15	80	120	120	70	180
PORT USED		-	-	-	A	A	A	B	B	B	C	C	C	D	D	D

I/O BOX TYPE

TEST NUMBER		46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
TYPE OF EXTINGUISHER		HALON 1211														
COVER POSITION	UP	✓	✓	✓												
	DOWN				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
MAXIMUM THERMOCOUPLE READINGS	1	268	118	261	591	244	51	100	270	37	468	373	230	262	180	277
	2	313	124	396	603	243	69	384	275	139	399	330	208	235	298	215
	3	229	185	151	320	162	127	221	112	118	195	209	192	196	109	104
	4	155	199	105	203	122	106	172	125	120	98	109	128	145	102	121
	5	128	136	199	125	114	117	249	112	125	192	88	109	111	109	129
	6	335	418	349	157	389	219	100	312	293	103	312	337	253	375	259
EXTINGUISHMENT SUCCESS	YES		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	NO	✓														
WIND VELOCITY (MPH)		3	3	3	3	3	3	3	3	3	4	3	3	3	3	4
WIND DIRECTION (DEGREES)		190	70	180	90	90	100	130	70	120	0	90	90	70	30	90
PORT USED		-	-	-	A	A	A	B	B	B	C	C	C	D	D	D

I/O ACROSS STERN

TEST NUMBER		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
TYPE OF EXTINGUISHER		CO_2						HALON 1211						$NaHCO_3$					
COVER POSITION	UP	✓	✓	✓				✓	✓	✓				✓	✓	✓			
	DOWN				✓	✓	✓				✓	✓	✓				✓	✓	✓
MAXIMUM THERMOCOUPLE READINGS	1	78	161	434	201	338	372	398	465	348	340	335	354	340	348	393	152	424	392
	2	384	238	286	282	341	387	307	382	322	314	306	277	347	311	296	336	373	230
	3	449	548	404	375	337	333	329	322	328	319	309	295	303	296	337	384	321	291
	4	347	286	354	359	370	362	380	362	354	361	355	353	325	367	315	341	349	319
	5	329	293	422	332	421	419	482	401	384	401	361	328	358	389	394	378	370	310
EXTINGUISHMENT SUCCESS	YES	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	NO																		
WIND VELOCITY (MPH)		2	2	2	2	3	3	3	3	5	4	4	4	5	5	5	5	7	4
WIND DIRECTION (DEGREES)		300	300	300	310	310	300	300	310	310	310	300	0	320	310	310	340	320	310
HUMIDITY		66	65	66	66	64	64	62	62	60	60	60	60	60	60	60	60	58	58
AMBIENT TEMPERATURE		27	27	27	27	27	27	27	27	28	28	28	28	28	28	28	29	29	29

INBOARD FLUSH HATCH

TEST NUMBER		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
TYPE OF EXTINGUISHER		CO_2						HALON 1211						PURPLE K		
COVER POSITION	UP	✓	✓	✓				✓	✓	✓				✓	✓	✓
	DOWN				✓	✓	✓				✓	✓	✓			
MAXIMUM THERMOCOUPLE READINGS	1	147	214	409	149	358	346	383	329	321	357	208	334	220	386	291
	2	308	400	395	236	333	425	337	344	301	366	255	329	240	318	413
	3	295	432	354	377	480	482	407	360	445	365	356	476	310	457	295
	4	213	321	313	139	214	212	261	255	257	205	368	342	354	241	277
	5	236	398	308	436	461	482	405	326	352	266	356	437	184	323	151
EXTINGUISHMENT SUCCESS	YES	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	NO															
WIND VELOCITY (MPH)		3	4	4	6	7	5	5	5	3	5	6	5	4	4	3
WIND DIRECTION (DEGREES)		30	30	30	30	30	40	30	40	30	200	150	160	280	300	270
HUMIDITY		50	50	50	54	54	54	54	54	54	54	54	54	88	84	74
AMBIENT TEMPERATURE °C		32.4	32.9	33.2	32.3	32.6	32.8	33.3	33.7	32.9	33.2	32.4	33.3	26	27	27

INBOARD FLUSH HATCH

TEST NUMBER		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
TYPE OF EXTINGUISHER		PURPLE K			ABC											
COVER POSITION	UP				✓	✓	✓				✓	✓	✓			
	DOWN	✓	✓	✓				✓	✓	✓				✓	✓	✓
MAXIMUM THERMOCOUPLE READINGS	1	235	256	106	99	330	401	385	397	354	312	289	284	303	275	184
	2	319	332	340	201	307	439	338	290	361	248	364	310	352	324	339
	3	397	430	444	251	489	668	409	413	465	435	460	407	482	432	401
	4	387	319	309	198	268	358	287	236	324	281	294	289	288	287	299
	5	466	342	497	135	450	648	231	269	310	245	293	294	257		
EXTINGUISHMENT SUCCESS	YES		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
	NO	✓						✓								
WIND VELOCITY (MPH)		3	2	4	3	3	2	3	3	3	3	3	3	4	3	5
WIND DIRECTION (DEGREES)		240	40	40	20	360	360	360	30	20	60	10	30	30	10	30
HUMIDITY		68	60	60	58	58	60	60	58	58	60	60	60	60	60	60
AMBIENT TEMPERATURE ^{o}C		28	30	28	29	30	30	30	30	30	30.9	31.0	30.8	31.5	32	32.2

APPENDIX C

RECOMMENDATIONS FOR THE LOCATION OF EXTINGUISHER PORT
IN INBOARD/OUTDRIVE RECREATIONAL BOAT ENGINE COMPARTMENTS

1.0 BACKGROUND

The present design of typical I/O engine enclosures requires that the enclosure be removed or opened in order to use fire extinguishing equipment in the event of a fire in the engine/bilge area. Research performed by the Coast Guard R&D Center indicates considerable improvement in the fire fighting efficiency if a port is provided through which the equipment nozzle can be discharged without opening the compartment enclosure.

2.0 RECOMMENDATIONS

The test results reported established the desirability and improved effectiveness of fighting an I/O engine compartment fire without having to open the cover or hatch. The data did not indicate any one port location as being particularly more effective than another. However, from a purely practical standpoint, considering the typical machinery arrangement within the engine enclosure, a port located in the center of the forward side of the engine compartment at a height above the cockpit deck that will allow small portable extinguishers (Coast Guard Class BI) to be used in an upright position would be most desirable.

Port locations on the side of an engine compartment are not acceptable because of limited access. Similarly a port located on the top of an engine compartment does not allow for a portable extinguisher to be used in an upright position. This can result in extinguisher malfunctions. The port should be located so that no large obstacles such as an air cleaner or engine block would trap the extinguishing agent or prevent it from dispersing evenly throughout the engine compartment.

Four inches is the recommended port diameter in order to accommodate the horn of carbon dioxide extinguishers. The port cover should be attached in a manner which will permit easy access for the extinguisher nozzle yet not become a potential missile in the event of an explosion. A flush mounted hand grip should be provided for easy removal. Other arrangements such as a swing or sliding cover would be acceptable. Figures C-1 and C-2 illustrate the recommended location and arrangement for the port.

The port and attachment should be designed to remain intact with an explosive pressure of two psig or lower.

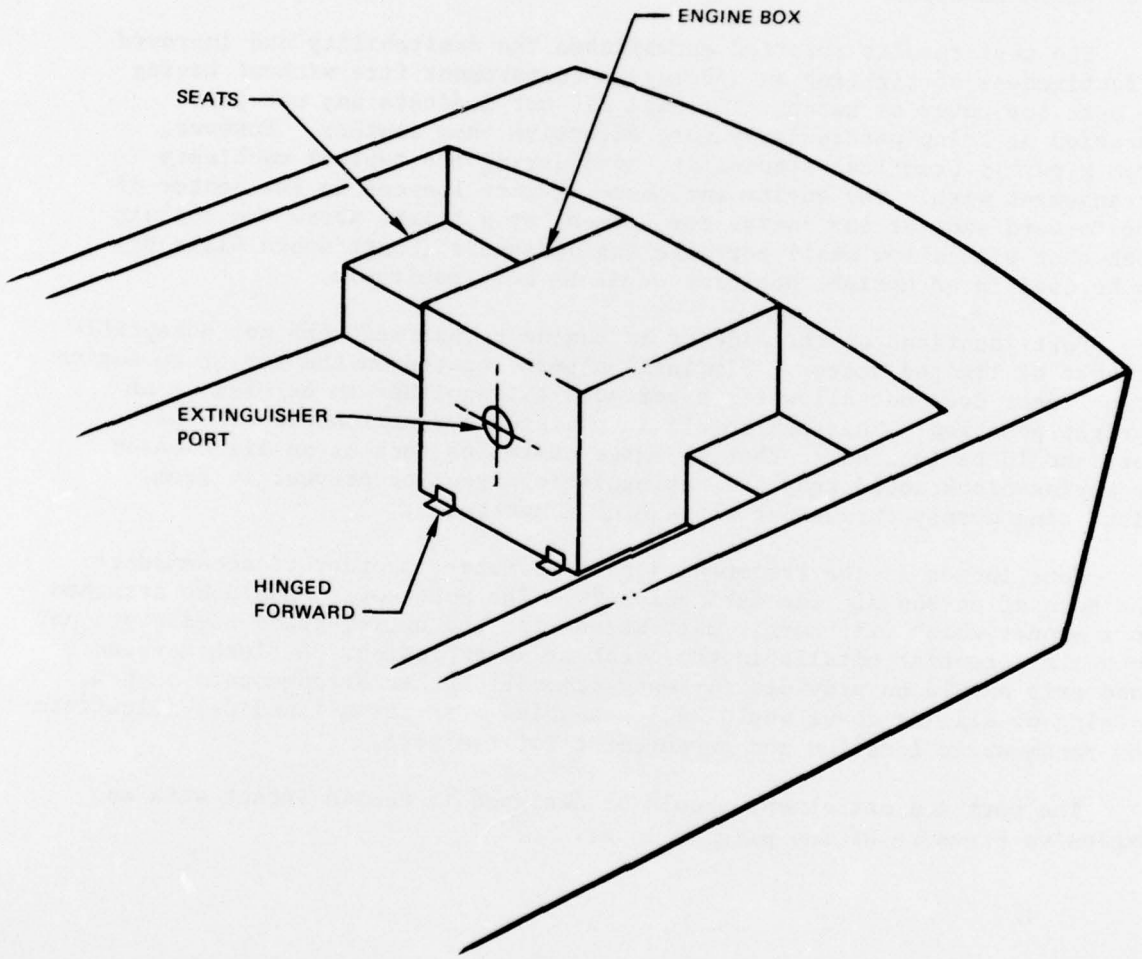

FIGURE C-1. EXTINGUISHER PORT - TYPICAL ARRANGEMENT

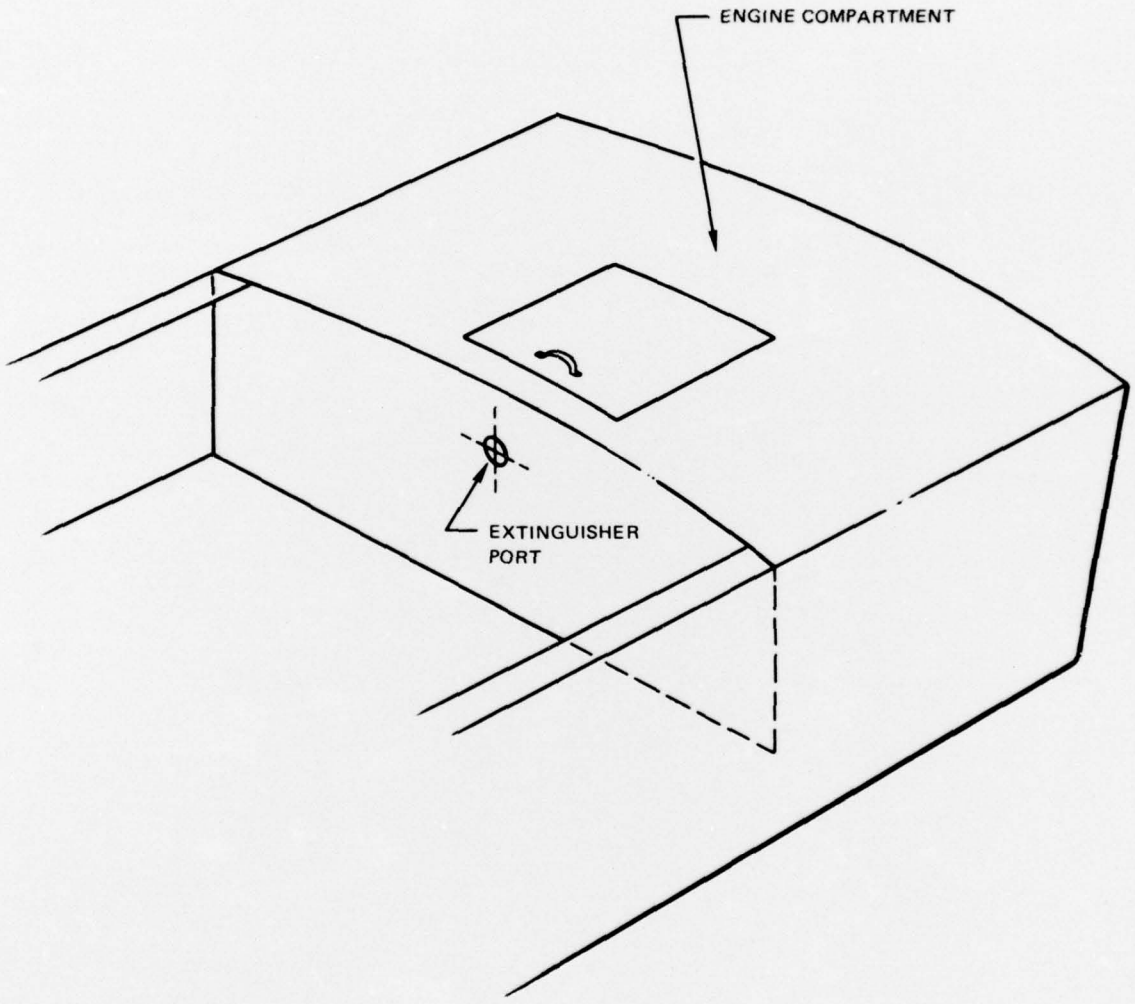

FIGURE C-2. TYPICAL EXTINGUISHER PORT ARRANGEMENT

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