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Report No. CG-D-50-77

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ESTIMATE OF THE POTENTIAL BENEFIT OF THE PRESSURE RELIEF VENT/FLAME DEFLECTOR CONCEPT USING IN-DEPTH ACCIDENT INVESTIGATION

JUNE 1977

FINAL REPORT

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

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16. Abstract

In-depth fire/explosion accident investigations were used to assess the potential benefits of the pressure relief vent/flame deflector concepts. Additional information obtained through analysis of the Coast Guard BAR file, telephone interviews with explosion victims and CG-357 data provided data from which numerical estimates in the reduction in the number of lives lost, number of serious injuries, and amount of property damage could be made.

In addition, in-depth accident investigations were used to obtain information on personal actions and reactions, fire fighting propensity and capability in an explosion/fire situation aboard recreational boats.

Based on the data reported herein, it is estimated that about 3 lives per year can be saved, over 50 injuries (burns) can be prevented, and about a million dollars of property damage can be prevented.

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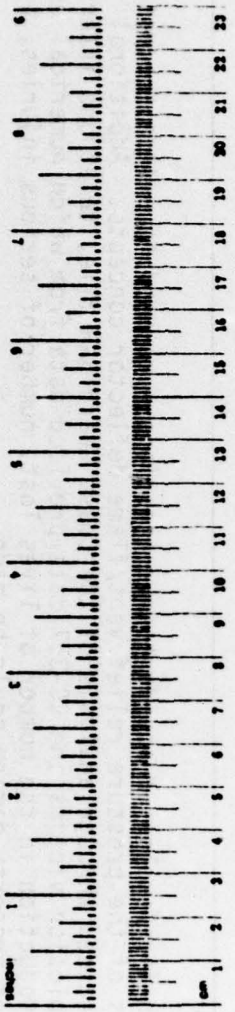
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

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

*1 in = 2.54 (exactly).



Approximate Conversions from Metric Measures

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

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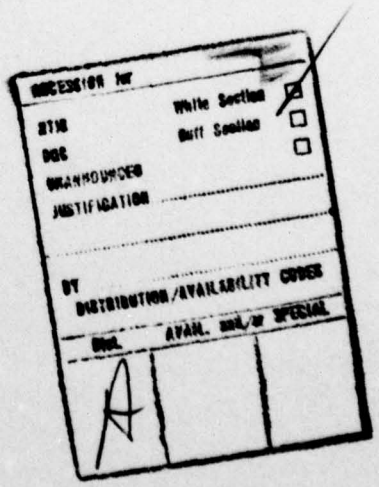

ESTIMATE OF THE POTENTIAL BENEFIT OF THE PRESSURE RELIEF VENT/FLAME DEFLECTOR CONCEPT USING IN-DEPTH ACCIDENT INVESTIGATIONS

1.0 INTRODUCTORY SUMMARY

According to CG-357 statistics, fire or explosion of fuel accounts for a small percentage of total fatalities resulting from recreational boating accidents; in fact, in 1975 fire or explosion of fuel caused only 12 fatalities, (0.8% of the total number of fatalities). Fire or explosion of fuel does, however, contribute significantly more to the number of injuries and amount of property damage. In 1975 there were 239 reported injuries (11% of the total number of injuries) related to fire or explosion of fuel. Property damage caused by fire or explosion of fuel in 1975 was reportedly about 2.5 million dollars (24% of the total property damage resulting from recreational boating accidents). It is believed that the total number of fire and explosion accidents reported and published in CG-357 account for about 10% of the actual number of accidents. It is also believed that nearly all of the fatal accidents involving fires and explosions of fuel are reported, leaving the unreported accidents accounting for additional property damage and injuries. If this is actually the case, then the values used and benefits estimated based on the CG-357 data will be conservative. Since it is likely that the more severe accidents have been reported, the additional property damage and injuries may not be proportional to the percentage of unreported accidents, and an accurate estimate of these unreported injuries and additional property damage cannot be made.

As part of the Coast Guard's program to increase the safety of recreational boating, research was initiated that would hopefully lead to a reduction in the destruction caused from fires and explosion of fuel. Part of this research involved evaluating the concept of pressure relief vents/flame deflectors in recreational boats.

References 1 and 2 document research that has been performed to evaluate the pressure relief vent/flame deflector for medium explosions in small craft. The following is a brief review of this research.

---

[1] Losey, R., Determination of Relief Vent Areas Required to Control Gasoline Explosions in Certain Boat Engine Compartments. Final Report, May 1975, DOT-CG-40672-A.

[2] Momany, N., Design Guidelines for Pressure Relief-Flame Deflectors for Inboard/Outdrive Recreational Boats, May 1975. DOT-CG-40672-A.

Typical inboard configurations, including I/O arrangements, have engine compartment covers which open in a manner that makes the engine accessible from within the boat. In the event of a vapor explosion in the engine compartment, pressures build up and eventually exhaust through these engine covers by opening or rupturing them into the passenger carrying area. The hot gases and, oftentimes, flames exhausting into the passenger area can severely burn the occupants of the boat. The concept of the pressure relief vent/flame deflectors is to release the pressure before it builds to more dangerous levels and deflect the gases and flames away from the boat occupants (Figure 1). These relief vents perform successfully only if the structures comprising the engine compartment are fairly air tight (provision must be made for combustion air) and strong enough so as not to fail before the vents are opened. If the vents are made light enough and are kept free to open, only minor modifications to production engine compartments need be made to insure that the vents operate properly.

The objective of the task reported herein was to estimate the potential benefit in the reduction of deaths, injuries and property damage from explosion accidents that may be obtained through application of the pressure relief vent/flame deflector (PRV) concept on recreational boats.

Ten fire/explosion accidents were investigated in-depth under this task, nine of which involved fires preceded by an explosion. Supplementary sources of data used in evaluating the relief vent potential benefits included:

- review of in-depth investigations of fire and explosion accidents that had been performed for the USCG in previous years;
- screening of accident data that was reported by telephone over the WATS line reporting system, which was set up by the Coast Guard to allow all Coast Guard districts to quickly alert certain accidents to a central location; and
- review of USCG Boating Accident Reports (BARs) that are kept on file at USCG Headquarters.

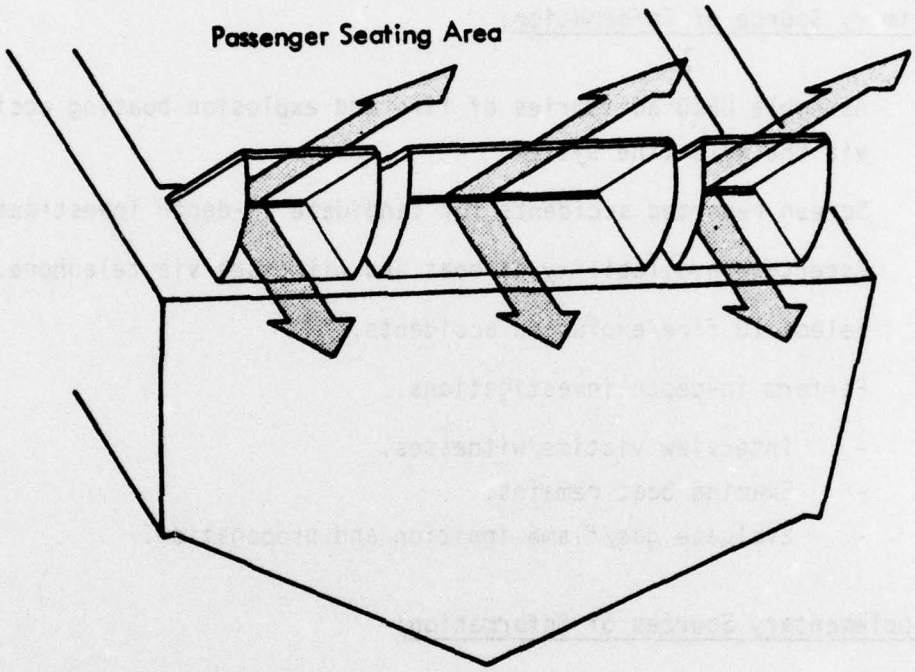

FIGURE 1. SKETCH OF PRESSURE RELIEF VENT/FLAME DEFLECTOR

2.0 APPROACH

In order to evaluate the possible benefit of PRV concept, the following approach was employed:

Primary Source of Information:

- Assemble USCG advisories of fire and explosion boating accidents reported via the WATS line system.
- Screen reported accidents for candidate in-depth investigations.
- Ascertain availability of boat and witnesses via telephone.
- [illegible] 10 fire/explosion accidents.
- [illegible]rform in-depth investigations.
  - Interview victims/witnesses.
  - Examine boat remains.
  - Evaluate gas/flame ignition and propagation.

Supplementary Sources of Information:

- Conduct telephone interviews with "other" fire/explosion accident victims/-witnesses.
- Review in-depth fire/explosion accident investigations performed by others.
- Review fire/explosion BARs on file at USCG Headquarters for 1974.

PRV Application Criteria:

Based on the criteria defined in Section 3.0 of this report:

- Evaluate the usability of the vent/deflector concept when integrated with the accidents investigated under Primary Sources of Information, above.
- Evaluate the usability of the vent/deflector concept when integrated with applicable accidents reviewed under Supplementary Sources of Information, above.

PRV Effectiveness

- Develop a measure of effectiveness to calculate reductions in death, injury, and property damage.
- Apply this measure to those accidents investigated and reviewed under this task effort.
- Calculate the total annual reduction of fatalities, injuries, and dollar value of property damage.

3.0 VENT/DEFLECTOR APPLICATION CRITERIA

In order to estimate if pressure relief vent/flame deflectors would have been beneficial in a given accident, we must first know the nature, propagation, and destructive effect of the explosion under investigation. Then we must ascertain if the vent/deflector concept would have been useful within that particular accident. Considering this methodology:

- If the explosion is of a level low enough that it is only heard and the results of it are not seen or felt, then pressure relief vent/flame deflectors would not have helped. A situation such as this would occur if the explosion did not dislodge the motor cover or adjacent structures and did not expel hot gases and/or flames into the passenger carrying area. It should be recognized that a low level explosion such as this has a great potential of being a larger explosion.

- At the other extreme is the situation where fuel vapors accumulate throughout the bilge for the entire length of the boat and the resulting explosion is of such magnitude that it lifts the entire deck from the hull sides. This type of explosion could be eliminated through proper isolation of fuel and engine spaces.

- Therefore, the types of explosions that most likely would benefit by pressure relief vent/flame deflectors are those in which the motor box or hatch or other adjacent structure is blown apart and hot gases and/or flames enter the passenger carrying area. We assume that the PRV correctly sized (Reference 2) and the surrounding structures are adequate to withstand the pressures. These assumptions are necessary since the concept of the relief vent/flame deflector depends upon these parameters.

4.0 PRIMARY/SUPPLEMENTARY ACCIDENT DATA

In accordance with the approach outlined in Section 2.0, several sources of information were used in evaluating pressure relief vent/flame deflectors. The primary source was in-depth investigations conducted by Wyle personnel. These investigations included interviewing persons on board the involved vessel as well as interviewing available witnesses, and examining the remains of the boat. Appendices A-J contain the complete investigation reports for each of the ten accidents. Each report describes the occupants' actions before, during, and after the accident, and provides data for reviewing the potential effect of a pressure relief vent. In addition, seven accidents that had been investigated in 1973 by Underwriters' Laboratories under contract to the USCG were also reviewed. These in-depth reports may be found in Reference 3.

Additional information was obtained from telephone conversations with persons involved in explosion accidents that were reported on the Accident Alert WATS line. During 1975 there were 152 fires/explosions reported, of which contact was made with persons involved in 37 of the accidents (these contacts are in addition to the in-depth investigations). Of these 37, 16 were fires without initial explosions and 21 were explosions generally followed by fires. Nine of the 21 explosion accident victims contacted disclosed information that was considered useful in the evaluation of the PRV concept.

A final supplementary source of information that was screened was the BAR file at USCG Headwuarters. Every tenth BAR for 1974 was reviewed. This amounted to 38 BARs involving 39 boats in all. Of these 39, 17 were explosions involving inboard or inboard/outdrive boats. The BARs were filled out properly and, for the most part completely, except in the area where a narrative of the accident is required. In most narratives only one sentence or sometimes just several words are provided. This did not present enough information to determine what happened during the accident. The information from the BARs was used only to determine a ratio of total fires to fires with an initial explosion.

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[3] Boating Accident Investiations 1973, Fire and Explosion. Underwriters' Laboratories AD 785 598, March 1974.

5.0 SUMMARY OF IN-DEPTH INVESTIGATIONS

The following table categorizes occupants' reactions in the 10 fire/explosion accidents investigated for this task. Following the table is a brief summary of each of the 10 accidents. The complete accident report for each investigation is contained in Appendices A-J.

SUMMARY OF OCCUPANTS'BEHAVIOR

F/E #	# POB	EXPLOSION LEVEL	TYPE BOAT	BLOWN OVERBOARD	CONSIDERED FIGHTING FIRE BUT DID NOT	FOUGHT FIRE	JUMPED OR HELPED OVERBOARD	CONSIDERED RETURNING TO BOAT TO FIGHT FIRE	RETURNED TO BOAT TO FIGHT FIRE
75-01	1	S	I/O				X		
	2	S					X		
75-02	1	M	I/O C				X		
	2	M					X		
75-03	1	L	Inbd			X			
	2	L							
	3	L							
	4	L							
	5	L							
	6	L							
75-04	1	D	I/O				X		
	2	D		X					
	3	D		X					
	4	D					X		
	5	D					X		
	6	D					X		
	7	D					X		
	8	D					X		
	9	D					X		
75-05	1	L	Inbd	X(1)*		X(3)	X(4)		X(2)
	2	L							X
	3	L							
	4	L							
	5	L				X			
	6	L					X		
75-06	1	L	I/O				X		

* Numbers indicate occupant action sequence

SUMMARY OF OCCUPANTS' BEHAVIOR, CONCLUDED

F/E #	# POB	EXPLOSION LEVEL	TYPE BOAT	BLOWN OVERBOARD	CONSIDERED FIGHTING FIRE BUT DID NOT	FOUGHT FIRE	JUMPED OR HELPED OVERBOARD	CONSIDERED RETURNING TO BOAT TO FIGHT FIRE	RETURNED TO BOAT TO FIGHT FIRE
75-07	1	D	I/O C				X		
	2	D					X		
	3	D					X		
	4	D					X		
	5	D					X		
75-08	1	S	I/O				X		
	2	S					X		
75-09	1	L	I/O				X	X	
	2	L			X		X		
	3	L					X		
	4	L					X		
75-10	1	L	I/O		X		X		
	2	L					X		

EXPLOSION LEVEL - L - Motor cover remained secure or fell back in place after explosion. (Low Level)
M - Motor cover undamaged but remained open after explosion. (Moderate Level)
S - Motor cover detached and blown out of engine area. (Severe Level)
D - Major structural damage and extensive fire. (Disastrous Level)

Type Boat - I/O - Inboard/Outdrive (typically with seats on both sides of motor cover.
I/O C - Inboard/Outdrive cruiser with engines below deck level.
Inbd - Inboard with engine below deck level.

75-01 - On a morning in early August, 1975, two men took their 24 ft (7.32 m) inboard/outdrive runabout for a short ride prior to an all day family excursion. They put approximately 10 gallons (37.85 liters) of gas into the boat and decided to anchor off a sand bar and swim. Upon re-entering the boat after the swim, the owner ran the blower for "a couple of minutes," then turned the ignition key. The engine compartment exploded. No attempt was made to fight the fire. Both men, uninjured, jumped into the water and swam for shore.

One man became fatigued and began to flounder before he reached shore. The other rescued him by towing him to shore.

Essentially, the boat burned to the waterline. Inspection of the remains showed that the major portion of the fire in the bilge was directly under the engine, and indicated that there was quite an accumulation of gasoline in that area.

75-02 - A man and his 20 year old son left for an offshore fishing trip at about 0800. Reaching their destination an hour later, they idled the engines to rig the lines. After rigging, the son stood in the door leading to the salon just forward of the aft deck fishing chair. His father, driving the boat from the flying bridge, heard and felt an explosion. He looked aft to seen his son with his clothes on fire on his hands and knees inside the cockpit.

After several attempts, the son managed to jump into the water. The owner shut down the engines and generator and grabbed two PFDs from a seat locker. He held onto the PFDs as he climbed over the front of the flying bridge and slid down onto the forward cabin top where a dinghy was stored. His intent was to unleash the dinghy and push it overboard. Although the small boat was secured to the cabin top with shock cords and a line with a slip knot, the owner found that he could not unhook the shock cords or release the slip knot, so he abandoned the idea of using the dinghy as a lifeboat. He walked aft into the cockpit and saw quite a bit of smoke rising into the salon from the engine room. Still holding the PFDs, he went forward again without pulling the handle on the CO_2 fire extinguisher system located in the cockpit, and again tried to unhook the dinghy. He couldn't. He jumped overboard with the two PFDs, put one on his son, and held the other under his arms.

The boat continued to burn and drifted away from them. Thirty minutes later, a boat came along, circled their burning boat and left. The owner was waving his PFD to attract attention, but because the boat had drifted approximately 0.375 to 0.50 of a mile (0.60 to 0.80 km) away and the seas were running three ft (0.91 m), he wasn't seen. Luckily, the operator of the other boat considered that survivors in the water could be some distance from the burning vessel, and came back and circled the boat. The survivors were found, picked up, and immediately transported to the hospital.

The owner's son was burned quite seriously. The owner received minor burns on his arms. The boat burned to the waterline and sank.

75-03 - The captain of a 58 ft (17.68 m) cruiser took his parents and friends for an afternoon boat ride. They cruised the inland waterway for about two hours, then entered the ocean for the return trip to their marina. Minutes later the captain smelled burning electric wire insulation. He immediately checked his ammeters and noticed that the starboard ammeter was filling with yellow smoke. At about that time the starboard engine stopped. His father took over the wheel while he went below to determine the extent of the problem. He opened the forward engine room hatch and saw open flames in the wiring behind the starboard engine. He felt sure that a short circuit was the cause of the fire and it was in the DC systems; therefore, he knew that he had to disconnect the batteries. He shut down the port engine and tried to radio for help. All three radiotelephones were dead. He entered the engine room and turned off the batter disconnect switches but noticed that the arcing continued. The shorting cables were on another circuit that was unfused and did not have a master disconnect switch. Because the batteries were located outboard of the engines and could not be reached, he couldn't disconnect the cables from the batteries.

All people on board donned PFDs. A boat came along and all POBs abandoned the burning vessel. Someone on shore saw the smoke and called the Coast Guard. They responded by sending a rescue boat to the scene. The fire was quenched, and the boat was towed ashore by the Coast Guard.

There were no injuries, but the boat suffered over $70,000 damage.

75-04 - The accident reported herein involved an 18 ft (5.49 m) inboard/outdrive, reportedly powered by a 165 hp engine. The type of accident was an explosion with a subsequent fire, which destroyed the boat beyond reasonable repair. There were no fatalities, but two of the nine people on board received severe burns.

At approximately 1230 on a morning in early July, 1975, two families, consisting of four adults and five children under 12 years of age, boarded the involved boat in preparation for an approximated 12 mile (19.31 km) trip to a picnic area located in northeastern Minnesota. The owner/operator started the engine and operated it at idle rpm for approximately 30 seconds. An adult male passenger had stood on the deck holding the boat until the other passengers were aboard and until the operator started the motor. After the motor had been running approximately 30 seconds, the male passenger put one foot in the boat and started to push off from the dock with the other foot. At this point, there was a medium to high intensity explosion in the engine compartment. One adult female and one two year old child who were seated in the stern starboard seat were ejected from the boat by the explosion. The other occupants either climbed out of the boat onto the dock or jumped into the water. Two of the children received severe burns and one child received moderate burns as a result of the explosion. The boat fire subsequent to the explosion was extinguished in approximately 15 minutes after the explosion by a local fire department. The boat was declared a total loss.

75-05 - The accident reported herein involved a 28 ft (8.5 m) wooden 165 model Ownes inboard cabin cruiser powered with a 1964 model 185 horsepower Chevrolet engine. The type of accident was an explosion and a short duration flash fire, resulting in minor to severe injuries to the six occupants aboard. The boat was moderately damaged by the overpressure created by the explosion. Very little fire damage was evident.

At approximately 2030 in early July, 1975, six people (four adults and two teenagers) boarded the involved boat at a marina located in northern Michigan. The party was to participate in the annual blessing of the boats ceremony. Approximately one hour before the occupants boarded the boat, the operator and the teenage male passenger had fueled the boat, bringing the 50 gal. (189.3 liter) tank to

approximately 1/2 full. During the fueling operation, the deck plates were removed and the engine compartment blower was running. After the occupants boarded, the operator started the engine in preparation for getting underway out of the harbor. There were 20 boats that were to participate in the blessing of the boats ceremony, and the involved boat was number 13. Approximately 15 minutes were required to get the boats in line to start the procession out of the harbor. The engine of the involved boat was running at idle speed during this time. Immediately after passing the harboar breakwater, the operator increased the engine rpm from 450 to 500 at which time the engine stopped. The operator restarted the engine and proceeded straight ahead at 500 rpm. After approximately five minutes, two explosions occurred in quick succession (0.5 - 2 seconds apart). The operator and one passenger stated that the force of the second explosion propelled the operator from the helm seat back over the transom into the water. The flash fire set the clothing of the other occupants afire. Four of the occupants either jumped or were thrown overboard, and the remaining two occupants were taken aboard a nearby boat manned by Coast Guard Auxiliary personnel. Three of the occupants were still hospitalized at the time of the investigation. The boat was towed back to the marina by a Coast Guard Auxiliary boat.

75-06 - The accident reported herein involved a 23 ft (7.0 m) inboard/outdrive boat powered by a 190 horsepower OMC engine. The type of accident was an explosion with a subsequent fire, which destroyed the boat beyond reasonable repair. No injuries were sustained by the sole occupant aboard.

At approximately 1500 in mid-October, 1975, the owner/operator of the involved boat set out on a fishing trip from a marina located in southeastern Virginia. He traveled up an island waterway to a calm bay arriving at approximately 1510. He fished in the bay for approximately one hour. During this time he had heard on his on board CB radio that the fishing was good in the inlet located approximately 20 minutes away. He traveled back down the island waterway to the inlet, arriving at approximately 1630. He started trolling at idle speed back and forth from the mouth of the inlet to approximately 1/2 mile out from the mouth of the inlet. He heard a low level explosion in the engine compartment and went aft to see what had happened. He moved the engine cover forward to look in the engine compartment. He saw flames in the lower forward section of the engine well. He was afraid that the

fuel tank located immediately forward of the fire would explode, so he grabbed a PFD and jumped overboard. He swam away from the boat thinking that an explosion would occur at any time. A small pleasure boat came to the aid of the operator approximately three minutes after he jumped in the water. The operator boarded the rescue boat and at this time noticed that the entire boat was ablaze. The rescue boat circled the burning boat at a safe distance for approximately six minutes, at which time a second boat arrived at the scene and called the Coast Guard on marine radio. The operator was then returned to the marina by the rescue boat. The fire was extinguished by a passing Navy vessel, and the boat was towed back to the marina by a local Coast Guard rescue boat.

75-07 - The accident reported herein involved a 28 ft (8.5 m) Seabird inboard/-outdrive powered by two 215 horsepower Mercury engines. The type of accident was an explosion with a subsequent fire, which destroyed the boat beyond reasonable repair. There were no fatalities, but one of the five people on board received severe burns.

At approximately 1130 in mid-December, 1976, five men ranging in age from 31 to 76 returned to a marina located in southern Louisiana after a weekend fishing trip. The boat was secured at the fueling dock and the fuel tank topped off by one of the occupants aboard.

While the boat was being fueled, the other occupants went inside the marina office, which was also a bar. The operator stated that he had turned the forward and aft bilge blowers on before the left the boat. After the boat had been fueled, the occupants talked to the marina owner until approximately 1150. At this time, the men started boarding the boat for the purpose of moving it diagonally across a small canal to its storage slip. The operator boarded and went directly to the helm position. Two of the other occupants boarded and were standing on the engine hatch covers. One occupant had one foot on the gunwale and one foot on the dock, preparing to board. The remaining occupant was standing on the dock, holding the boat until everyone was aboard and the engines started. According to the operator, a violent explosion occurred as he was sliding across the helm seat to the normal operating position. He stated that he had not turned an ignition key to the start position. The operator was hit in the back and neck by an unknown object which

knocked him face down on the deck. He was able to get out of the boat unassisted. The force of the explosion blew the engine hatch covers out of the boat. The occupants that were standing on the covers were thrown upward and came down in the engine compartment. One occupant landed back down across the starboard engine. The other occupant landed on the outboard side of the port engine. He was helped out of the boat by the marina attendant. The occupant that was in the process of boarding fell in the water between the dock and the starboard side of the boat. The occupant that was holding the boat was thrown back onto the dock. After the explosion, the aft half of the boat and entire bilge was ablaze with flame heights extending approximately 2 ft (0.6 m) above the deck. The fire was extinguished within ten minutes after the explosion by a large dry powder type fire extinguisher that was located on the fueling dock. The boat was declared a total loss by the insurance company. At the time of the investigation, the occupant that was standing on the port engine hatch cover was still hospitalized and had lost nine toes as a result of the fire.

75-08 - The accident reported herein involved an 18 ft (5.5 m) Larson inboard/-outdrive runabout powered by a 155 horsepower Buick engine. The type of accident was an explosion with a subsequent fire, which destroyed the boat beyond reasonable repair. There were no injuries or fatalities resulting from the accident.

At approximately 1630 in mid-July, 1976, two men departed a marina located in North Central Ohio, destined for a fishing location approximately 10 mi. (16.1 km) out in Lake Erie. The boat had been fueled just prior to leaving the marina.

The men traveled approximately 300 ft (91.4 m) to a canal that led to the lake, turned into the canal and headed toward the lake at idle speed. The men smelled something, but thought the odor was coming from a marsh area along the canal. The men could not describe the odor but stated that it did not smell like fuel. After traveling approximately 2000 ft (609.6 m) down the canal, the operator noticed that the carpet in front of the engine compartment was wet and the carpet had wrinkled. He suspected the carpet was saturated with fuel because water had never caused the carpet to wrinkle. He started turning the boat around to go back to the marina.

In the turn the men smelled fuel and decided to run the boat aground. Before the boat reached shore, an explosion occurred in the engine compartment with a resulting fire. The men jumped overboard and swam ashore. The boat burned to the waterline before the fire was extinguished by a local fire department.

75-09 - The accident reported herein involved a 22 ft (6.7 m) I/O cabin cruiser powered by two 130 horsepower engines. The type of accident was an explosion with a subsequent fire, which destroyed the boat beyond repair. The market value of the boat was estimated to be between 10 and 12 thousand dollars. There were no injuries sustained by any of the four occupants aboard.

At approximately 0500 in mid-July, 1976, a fishing party consisting of three adult males and one female child got underway from a private dock located in east central South Carolina destined for a fishing area 30 to 50 miles off the east coast. The operator noticed when they left the dock that the engines were not running properly. After being underway for approximately three minutes, a passenger observed that black smoke was coming from the exhaust; shortly thereafter, the starboard engine stopped. The operator restarted the engine and asked one of the passengers to raise the motor cover and see if he could see anything that would cause the engine to run rough. The passenger raised the cover, and immediately the engines began to run normally. It was too dark for the passenger to see the engine clearly, so he lowered the cover and asked another passenger to get a flashlight. As the passenger started forward to get the flashlight, an explosion occurred in the engine compartment. The occupants saw flames coming out of the transom hatch cover and decided to jump overboard. Before jumping overboard, the operator grabbed four AK-1 PFDs. The occupants held to the PFDs and swam approximately 1/8 mile to shore. The boat drifted to a sandbar and burned to the waterline.

75-10 - The accident reported herein involved a 20 ft (6.1 m) inboard/outdrive (jet outdrive) cabin cruiser powered by a 205 horsepower engine. The type of accident was an explosion with a subsequent fire, which destroyed the boat beyond reasonable repair. The estimated value of the boat was $6,000. There were no fatalities or injuries resulting from the accident.

At approximately 0930 on May 16, 1976, two men arrived at a marina located in Port O'Conner, Texas after a fishing trip in the Gulf of Mexico. The men had traveled at top speed (approximately 25 mph (40.2 kph) from the fishing area located approximately 12 mi. (19.3 km) off shore. When they reached the launch area at the marina, several boats were waiting to be hoisted out of the water. The men cruised around in the area near the boat hoist at 4-5 mph (6.4 - 8 kph) for a period of approximately five minutes. The boat was cruising parallel to the shore at a distance of approximately 50 ft (15.2 m) when a low level explosion occurred in the engine compartment. Shortly after the explosion, the operator and passenger saw flames coming from under the front and sides of the engine cover. The men did not attempt to extinguish the fire, because they were afraid the fuel tanks installed on either side of the engine would explode. The men exited the boat through the cabin forward window and boarded the cabin cruiser that had witnessed the accident and had maneuvered to the bow of the burning boat. The boat drifted ashore and the fire was extinguished, within 15 minutes after the explosion occurred.

6.0 BENEFIT ESTIMATE FOR PRV CONCEPT

In order to estimate the potential benefit which may be obtained from the pressure relief vent/flame deflector concept, three factors which must be determined are:

- The total destruction caused by explosions and resulting fires (death, injuries, property damage).
- The number of cases that may have a reduction in the accident consequences (death, injuries, property damage).
- The expected benefit of the pressure relief vent/flame deflector concepts on individual cases.

These three factors can then be combined to determine the total potential benefit that may be obtained through the pressure relief vent/flame deflector concept application.

6.1 Accident Consequences Caused By Explosions

The first factor was the total destruction caused by explosions. Data for deaths, injuries, and property damage in CG-357 is listed under the heading, "fire or explosion of fuel." Since the pressure relief vent/flame deflector concept was assumed to be useful only if an initial explosion had taken place, then the CG-357 data could not be directly used. The relative amount of accident consequences for fires only and fires preceded by explosions needed to be estimated. The way chosen to estimate the relative damage between fires only and explosions was to use the data available on the ratios of explosions to fires with no initial explosion and estimate the damage based on these ratios.

As mentioned in Section 4.0, Boating Accident Reports on file at USCG Headquarters were used to determine a ratio of total fires only to fires preceded by an initial explosion. The following table summarizes the 38 BARs reviewed (39 boats were involved) by propulsion type and presence of initial explosion.

	INBOARD/OUTDRIVE	INBOARD	OUTBOARD
TOTAL # OF BOATS	17	11	11
INITIAL EXPLOSION	9	8	1
% WHICH INVOLVED INITIAL EXPLOSION	53	73	9

Previous work (References 1 and 2) had only considered the I/O configuration where the engine is generally above cockpit deck level and there are passenger seats adjacent to the engine compartment cover. Although this appears to be the configuration that is most readily adaptable to the PRV concept, proper design and construction utilizing the same concepts can also be applied to vessels in which the engine (either inboard or I/O) is located beneath the cockpit deck such as is typical on larger cruisers. For this reason benefits will be estimated for both I/O and Inboard configurations. Benefits for each type of boat will be estimated separately utilizing the available data. Outboard powered boats will not be included in this analysis. The bottom line in the table above shows that, of the BARs reviewed, accidents that involved inboard/outdrive boats involved an initial explosion in 53% of the cases; and for inboard boats, 73% involved an initial explosion. From this it can be estimated that damage caused by accidents involving an initial explosion is approximately:

- 0.53 times the total damage reported in CG-357 for "fire or explosion of fuel" for craft powered by inboard/outdrive engines, plus,
- 0.73 times the total damage reported in CG-357 for "fire or explosion of fuel" for craft powered by inboard engines.

6.2 Cases that Benefit from Pressure Relief Vent/Flame Deflectors

The next factor that needed to be determined was the percentage of fires with an initial explosion that would benefit from the pressure relief vent/flame deflector concept. This was accomplished by evaluating the 10 in-depth investigations performed by Wyle, seven accidents investigated by Underwriters' Laboratories and the information obtained through the telephone contacts with persons involved in fires/-explosions in 1975.

Of the 10 in-depth investigations performed by Wyle, nine involved initial explosions. Based on the criteria of Setion 3.0, of these nine, relief vents were considered to be beneficial in seven instances.

In reviewing the seven explosions that were investigated by Underwriters' Laboratories (Reference 3), it was determined that pressure relief vents would have been beneficial in three of the seven cases.

Of the 37 persons contacted that had been involved in fire/explosion accidents in 1975, 21 were involved in initial explosions. From these 21, only nine provided information that was considered useful in the evaluation of pressure relief vent/-flame deflectors. Of these nine explosions, information indicated that pressure relief vents would have been beneficial in five of the cases.

The following table summarizes the potential benefits by boat type and data source.

	TOTAL REVIEWED		BENEFIT FROM PRV	
DATA SOURCE	I/O	INBOARD	I/O	INBOARD
WYLE IN-DEPTH	8	1	6	1
UL IN-DEPTH	2	5	1	2
TELEPHONE CONTACTS	4	5	2	3
TOTALS	14	11	9	6

From this table it can be seen that of the 14 cases that involved I/O configuration boats, 9 cases may have benefited from the use of the PRV concept. Of the cases reviewed involving inboard powered boats, 6 of 11 cases may have benefited from this concept.

The data studied shows that 9/14 or 64% of I/O and 6/11 or 55% of Inboards involved in explosion related accidents could possibly benefit from the use of PRV. It must be recognized that these values are based on the data that was reviewed for this task which may not be totally representative of the actual population. However, it is felt that these figures do provide some basis for an estimate of potential benefits and, if anything, are considered conservative.

6.3 Estimated Benefit of Relief Vent Concept

The third factor that was to be determined was the actual benefit that could be realized for a given case. Section 6.2 estimated the number of cases that could benefit from pressure relief vent/flame deflector. It is realized that in these cases the pressure relief vent/flame deflector would not eliminate 100% of the accident consequences. The reduction in accident consequences on a per accident basis must, therefore, be estimated. Based upon the data herein, and laboratory tests and evaluation of prototype PRV installed in boats, a reasonable engineering estimate for the effectiveness of a PRV is considered to be between 85 and 95%. For calculation purposes we will use 90%.

Based on the data presented in Sections 6.1 and 6.2, the following analysis was made:

For a given class of boat propulsion type, the reduction in accident consequences as reported in CG-357 that could be achieved can be expressed as follows:

> (% of fire/explosion accidents involving initial explosion) times
> (the % of explosion cases that would be helped by relief vents) times
> (the reduction in consequences for any given cases afforded by the relief vents).

For I/O craft, the reduction in accident consequences would be

(0.53) (0.64) (0.90) = 31%

For inboard craft the reduction in accident consequences would be:

(0.73) (0.55) (0.90) = 36%

These percentages may be applied to CG-357 statistics to obtain benefit estimates. Using statistics for the years 1974 and 1975, we obtain the following table of average yearly accident statistics for reported fires or explosions involving fuel.

	INBOARD/OUTDRIVE	INBOARD
FATALITIES	3.5	5.0
INJURIES	45.0	104.5

This data indicates a possible benefit of (0.31) (3.5) + (0.36) (5.0) = 2.9 lives saved and a reduction of (0.31) (45.0) + (0.36) (104.5) = 51.5 reported injuries as a result of use of the PRV.

An estimation of the reduction in property damage is more difficult since this data is not tabulated by boat type in CG-357. We may make a rough estimation by using the relative proportion of vessels to estimate the amount of property damage for each type of boat.

1974 and 1975 CG-357 statistics indicate that approximately 31% of the small craft involved in fires or explosions of fuel are inboard/outdrives and 50% are inboards. The average yearly property damage for these accidents for 1974 and 1975 is reported as $2,470,500. We may now estimate the reduction in property damage as

($2,470,500) [(0.31) (0.31) + (0.50) (0.36)] = $682,100.

This estimate is probably conservative and, considering an estimated reporting rate of perhaps 10%, may be considerably higher.

7.0 QUALIFICATIONS/CONCLUSIONS

The evaluation of the overall benefit of the pressure relief vent/flame deflector concept was based on several assumptions. It is realized that some of these assumptions may not be entirely true; however, at the time, they were made from the best data available. The major assumptions used were as follows:

1) The ratio of explosion related fires to fires beginning without an explosion in the sample of BARs reviewed is representative of the actual ratio.

2) The ratio of explosions that would be helped through the use of relief vents to those that could not be helped is represented by the sample of explosions investigated.

3) The engineering estimate of 90% effectiveness for the relief vents in cases when they are useful assumes that the occupants can and do put out fires that occur after the initial explosion.

Although the ratio of I/Os, inboards, and outboards in the sample of BARs reviewed differs from the ratio listed in CG-357 for 1974 (the year from which the sample was taken), it is felt that the sample of inboards and inboard/outdrives reviewed is representative of the population of inboard and inboard/outdrives, since there is nothing at the present time to indicate otherwise. If this is indeed true, then the reduction in fatalities, injuries, and property damage that could be realized through the use of relief vents on a yearly average could be:

Fatalities	2.9 lives
Injuries	51.5 persons
Property Damage	$680,000

These estimates are valid only if all inboards and inboard/outdrive boats are equipped with pressure relief vents/flame deflectors. The estimate of benefit per year as they are introduced in new boats, and the cost of compliance were not attempted in this task. Since the Coast Guard believes that the data in CG-357

represents only about 10% of the actual number of accidents involving fires and explosions, the total benefits estimates are conservative. The benefits calculated cannot be directly scaled based on the suspected number of unreported accidents. Even though the number of accidents reported may only be 10% of the total number that occurred, the number of deaths, injuries, and amount of property damage are probably more than 10% of the total. It is believed that nearly 100% of the accidents involving deaths are reported, and accidents resulting in severe injuries and extensive property damaged are generally reported. It is the accidents that involve only minor injuries and relatively slight property damage that are believed to account for the majority of the unreported accidents. This makes the benefit estimates conservative but not off by 90% as is suspected by the number of reported accidents.

The data in Section 6.3 indicate that the PRV concept, if fully implemented, might save about one-third of the 8.5 lives per year that are lost due to explosion/fires on inboards and inboard/outdrives. This is a rough estimate based upon several parameters estimated from a relatively small sample. Indeed, to narrow the range of possible benefits (0 to 8.5 lives per year) in a more precise manner would require a much more detailed analysis. Similar arguments hold for injuries. In terms of property damage, the benefit estimate of nearly $700,000 per year with full implementation was based on assumptions such as those stated on the previous page. These assumptions are invalidated by the statements in the paragraph above. Thus, an accurate assessment of the benefits in terms of property damage would also require a study of considerable depth. Finally, it should again be noted that the indicated benefits are based upon full implementation. Obviously, not all boats would be equipped with PRVs even if a standard were passed that required them, since it would be some time before full implementation would occur. Until that time, only a fraction of the indicated benefits would be observed.

APPENDIX A

ACCIDENT INVESTIGATION REPORT

Date of Investigation: Mid-August, 1975

Date of Accident: Early August, 1975

Investigation: Fire/Explosion No. 75-01

SUMMARY — WYLE ACCIDENT NO. 75-547

On a morning in early August, 1975, two men took their 24 ft (7.32 m) inboard/outdrive runabout for a short ride prior to an all day family excursion. They put approximately 10 gallons (37.85 liters) of gas into the boat and decided to anchor off a sand bar and swim. Upon reentering the boat after the swim, the owner ran the blower for "a couple of minutes," then turned the ignition key. The engine compartment exploded. No attempt was made to fight the fire. Both men, uninjured, jumped into the water and swam for shore.

One man became fatigued and began to flounder before he reached shore. The other rescued him by towing him to shore.

Essentially, the boat burned to the waterline. Inspection of the remains showed that the major portion of the fire in the bilge was directly under the engine, and indicated that there was quite an accumulation of gasoline in that area.

1.0 BOAT OCCUPANT DATA

Operator/ Passenger	Sex	Age	Weight	Swimming Ability	Boating Experience	Formal Boating Instruction	PFDs Worn
Operator	M	28	180 lbs (81.6 kg)	Excellent	Excellent	No	No
Passenger	M	27	155 lbs (70.3 kg)	Good	Good	No	No

The owner is the son of very rich parents. He is a college graduate and owns his own business, and doesn't really have to work at all. Much of his time is spent boating and flying his small plane.

He seemed to attract people of the same socio-economic status. During the interview, which was held at his father-in-law's house, there seemed to be a steady stream of friends entering the house. They felt completely at home, since they made their own coffee and snacked from a refrigerator at will.

He seemed quite self assured, not a bit nervous, and quite willing to help in any way possible. Throughout the interview, the owner, his wife, her father and mother, the passenger, and two friends entered the conversation.

He was definitely safety conscious. His boat was equipped with both a VHF and CB radio telephone, a 10 lb (4.54 kg) CO_2 fire extinguisher, spare engine parts, light bulbs, and had recently been inspected by the Coast Guard Auxiliary.

2.0 ENVIRONMENT

On the morning of the fire, the sky was overcast but the forecast called for it to lift early in the day. It actually lifted about 0900. The air temperature was around 80°F (27°C) with the water temperature in the low 70°F (21°C) range. The wind was from the south at 4-5 mph (6.44-9.05 kph). Essentially, the surface of the water where they were anchored was smooth.

3.0 NARRATIVE

The following narrative was compiled from conversations with the owner/operator, his wife, her father and mother, the passenger, and Coast Guard representatives.

3.1 Pre-Accident

The owner, his family, his friend, and his friend's family had planned a day trip to an island about 30 miles (48.29 kilometers) off the coast. The owner awakened about 0700. About 0930, he and his friend left for the boat to check it out and gas it up while the wives were getting the kids and the food ready.

Prior to starting the engine in the morning, the operator claimed that he always checks the oil and sniffs for fuel vapors. (He, in fact, performed that task on this particular day.) However, on subsequent startups on the same day, he never opens the engine hatch. Instead, he runs the blower for a couple of minutes, then starts up.

They left their dock and checked the gas. One tank registered 1/4 and the other registered 3/8. Upon arriving at the gas dock, the two occupants found that they had left the bulk of their money at home. They had $ 10.00 between them. They bought $ 6.00 worth of gas, or about 10 gallons (37.85 liters) and left the gas dock for a spin around the harbor. At that point, the tank that had registered 1/4 now registered 1/2. The gauge on the other tank still registered 3/8.

It was a beautiful morning, so they thought they would anchor off a sandbar and dive for conch while they waited for the girls to get ready. They anchored and dove for about one-half hour. When they were finished, the owner climbed into the cockpit and the passenger climbed onto the foredeck to retrieve the anchor. (These two had been boating together for a long time and this was their standard procedure. The owner would start the engine then idle forward towards the anchor while the passenger hauled in the anchor line.)

The owner moved the blower switch to the on position and policed the cockpit for a "couple of minutes." He turned on the radio and adjusted the volume. He then positioned himself behind the wheel and turned the ignition key.

3.2 Accident

An immediate explosion resulted. The owner didn't see any flames, but heard a muffled "poof" and felt the searing heat and the force of the shock wave on his back. The passenger, however, was facing aft and saw flames as the two seats beside the engine box were blown forward. The engine box didn't move.

Neither of them considered fighting the fire nor did they consider donning a PFD. Both of them immediately jumped overboard and began to swim for shore. Their basic ambition was to get as far away from the boat as possible in the shortest amount of time.

It was interesting to note that the fire extinguisher had been replaced a few weeks prior to the fire. The passenger's uncle who works for the local fire company happened to be on board and noticed the 2.5 lb (1.13 kg) dry chemical fire extinguisher that was hanging on a clip close to the helm. He told the owner that that type wasn't large enough to be of any value and immediately furnished him with a 10 lb (4.54 kg) CO_2 fire extinguisher which was mounted near the helm at the time of the fire.

3.3 Post Accident

The boat was anchored on a sandbar in about 3-4 ft (.91-1.22 m) of water. However, the sandbar was about 100 yards (91.44 m) from shore. The water was deep for the majority of that 100 yards (91.44 m). The passenger, although he said he was a "good" swimmer, couldn't make the shore. He floundered when a little over half way. The owner rescued him by turning him onto his back and towing him the rest of the way.

The owner figured that it took him 20 minutes to swim to shore. Twice during the swim, the horn on the boat blew. Each time he looked back to see the boat engulfed in a cloud of thick black smoke.

Local residents of the beach front houses in the area called for an ambulance, the fire company and the harbor patrol. The ambulance took the two men to the hospital where the passenger was treated for shock and immersion and the owner was examined and released.

Meanwhile, the fire trucks on shore were of no use in extinguishing a fire on a boat 100 yards (91.44 m) away. The Harbor Patrol boat wouldn't get close enough to the burning boat to cut the anchor line and tow it in. However, the local harbormaster came out in his boat, cut the anchor line and towed the burning hull to the beach where the firemen quickly extinguished the blaze.

The hull was towed to the nearest road and trucked to a local marina. It was to be cut up and disposed of in the local dump.

3.4 Other Information

The families were out on the boat on the day before the fire. Sometime during their excursion, one of the children who was sitting on one of the aft seats beside the engine box complained of smelling gas fumes. Their father, the owner, dismissed this as being exhaust fumes, since they were traveling at a slow speed downwind at the time.

4.0 FACTS FROM THE BOAT INSPECTION

The fiberglass boat was a 1971 24 ft (7.32 m) Sea Ray single engine (OMC - 215 hp) inboard/outdrive. It weighed 4400 lb (1995.8 kg) and had a 96 in. (2.4 m) beam. Two saddle tanks were located on both sides of the cockpit between the cockpit coaming and the hullsides. Filler pipes and vents were located port and starboard near the forward end of the tanks. The pickup tubes were located aft and were connected to elbows, shut off valves and copper tubing, to a tee fitting, then to the stringer and fuel pump via a short length of flexible tubing.

As can be seen from the photos, there wasn't much left of the boat. The carburetor and backfire flame arrestor seemed to be in good shape. Evidence showed that there was a continuous supply of gas in the bilge, so the carburetor was discounted as the source of the fuel leak.

Examination of the fuel pump showed it to be almost totally destroyed. The area surrounding the pump was destroyed to the extent that it was impossible to determine the problem that led to the initial source of the fuel leak. However, since the starter motor was directly behind the fuel pump, the following assumption has been made.

There is a possibility that the leak could have occurred the day before at a point that was between the 3/8 and 1/2 level of the tanks. Neither tank had an anti-siphon valve according to the boat manufacturer, so as long as the gas level in the tank was below the point where the leak occurred, there would be no problem. While running, the leak would not be noticeable because it would be on the suction side of the pump. However, when the tank was filled to 1/2 earlier that morning, the fuel level within the tank became higher than the level of the leak. When the engine was shut off for the half hour of diving, a siphon effect was set up which provided a steady flow of gas into the bilge. The residual heat of the block heated the engine compartment to the point where leaking gas was vaporized into an explosive mixture. When the operator turned the ignition key, the mixture was ignited by a spark from the starter motor or solenoid switch.

5.0 PSYCHOLOGICAL AND HUMAN FACTORS

The owner/operator only sniffed the bilges at the beginning of each boating outing. Therefore, he made the assumption that if he didn't smell gas in the engine compartment at the beginning of the day, there would be no gas leakage throughout the day. He claimed that he operated the blower for a couple of minutes each time he restarted the engine throughout the boating day.

He also claimed that he was quite safety conscious and carried spares on board, including fan belts and light bulbs. However, he didn't know that the two gas tanks were equipped with shut off valves and he was totally unaware of the routing of the gas lines from the tank to the engine. Therefore, although he was safety conscious in some respects, he had never made a visual check of the fuel feed system in the four years that he had owned the boat.

In addition, the owner didn't heed the warning of his daughter when she complained of smelling gas fumes the day before. If he had stopped the boat at that time and lifted the engine hatch, he may have been able to have seen the leak or at least to have smelled the fumes. In that case, the accident would not have happened.

Once the fire started, the two men immediately jumped overboard. The 10 lb (4.54 kg) CO_2 fire extinguisher may very well have been large enough to extinguish the blaze. With the seats out of the way, the CO_2 could have been directed to the base of the motor area. A small door on the forward side of the engine box would have been handy for stuffing in the end of the fire extinguisher. But the owner was so afraid of a second explosion that he could only think of getting as far away as possible. In fact, he was unwilling to take the few extra seconds to grab a couple of PFD's from the forward storage area. Because of this, his friend came close to losing his life when he found that he couldn't make it to shore.

Therefore, the human errors leading up to the fire and also after the fire began were:

1. The owner was warned of a gasoline leak but did nothing about it.
2. The owner sniffed for fumes only prior to the first startup of the day. He never opened the engine box after that.
3. He jumped overboard and attempted to swim 100 yards (91.44 m) without his PFD.

All three errors are of the type that could be reduced through some sort of education methodology.

6.0 PROBABLE CAUSE OF ACCIDENT

Fuel leaked into the bilge area by way of the engine. When the starter was energized, the fuel vapors were ignited. A possible explanation for the fuel leakage is described in Section 4.0 above.

7.0 DYNAMICS/ANALYSIS OF THE ACCIDENT

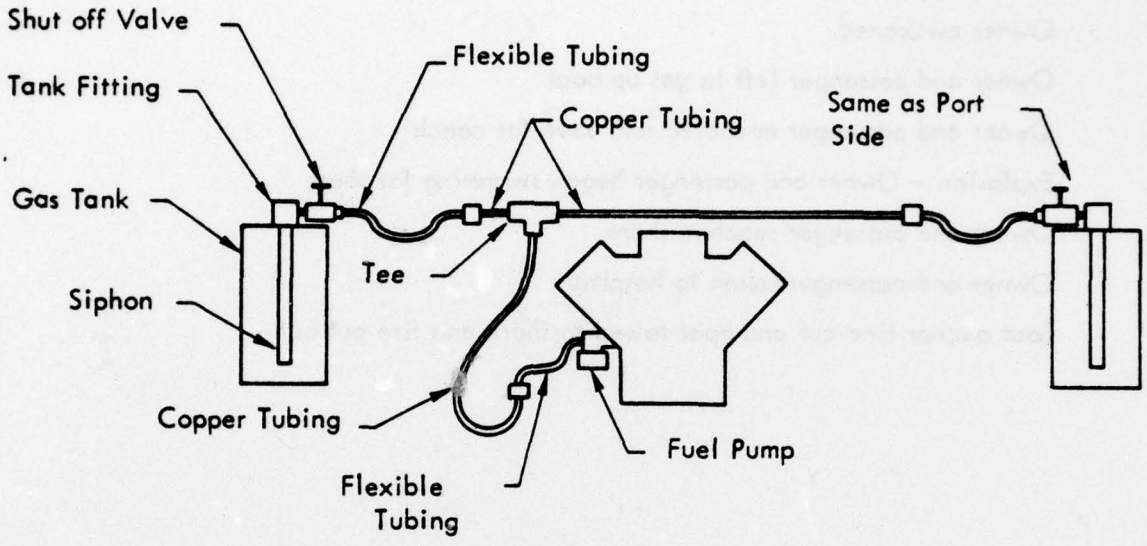
The fire started at the forward port corner of the engine. The resultant explosion pushed the two rear seats forward, thus providing a source for more oxygen to feed the fire. The interior and deck of the boat were totally destroyed; therefore, it was impossible to trace the path of the fire as it spread. There must have been an accumulation of gas under the aft portion of the engine, because a good portion of the aluminum bell housing had melted. This tends to support the siphoning theory since quite a puddle of gas could have been siphoned into the bilge in the one-half hour that the occupants had swum. The gas would have concentrated in the lowest portion of the bilge which, in that boat, is directly under the bell housing.

No one was injured by the explosion because no one was sitting on the aft seats. However, serious injuries would have been inevitable if the aft seats had been occupied. Pressure relief valves coupled with locked seats and engine cover would have directed the hot gasses aft where they would not have hurt anyone in the boat.

The operator may have stayed aboard and made an attempt to fight the fire if: (1) the pressure relief valves had done their job, (2) the engine cover had had a small port through which the nozzle of a fire extinguisher could be directed, and (3) he had had some sort of education instructing him in the principles of pressure relief valves and how to put out a fire aboard a boat. Without the education, he may very well have panicked and jumped overboard as happened in this instance.

TABLE I. TIME LINE OF EVENTS IN ACCIDENT

0700	Owner awakened
0930	Owner and passenger left to gas up boat
1000	Owner and passenger anchored and dove for conch
1030	Explosion - Owner and passenger began swimming for shore
1050	Owner and passenger reached shore
1115	Owner and passenger taken to hospital
1130	Boat anchor line cut and boat towed to shore and fire put out



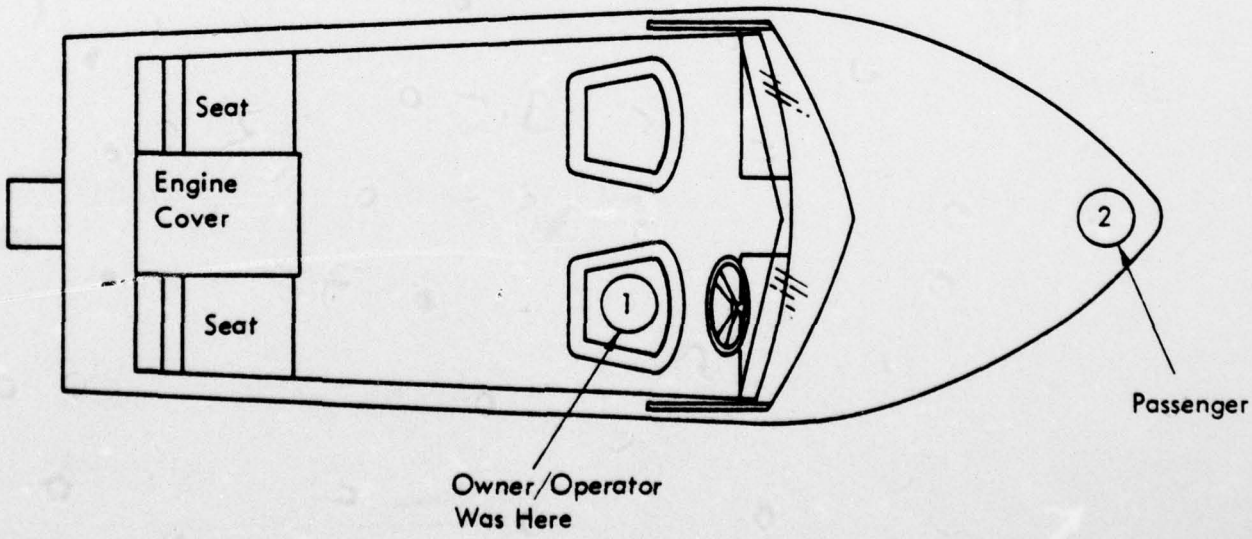


Figure 1. Fuel System Schematic And Plan Of Boat

Figure 2 Profile

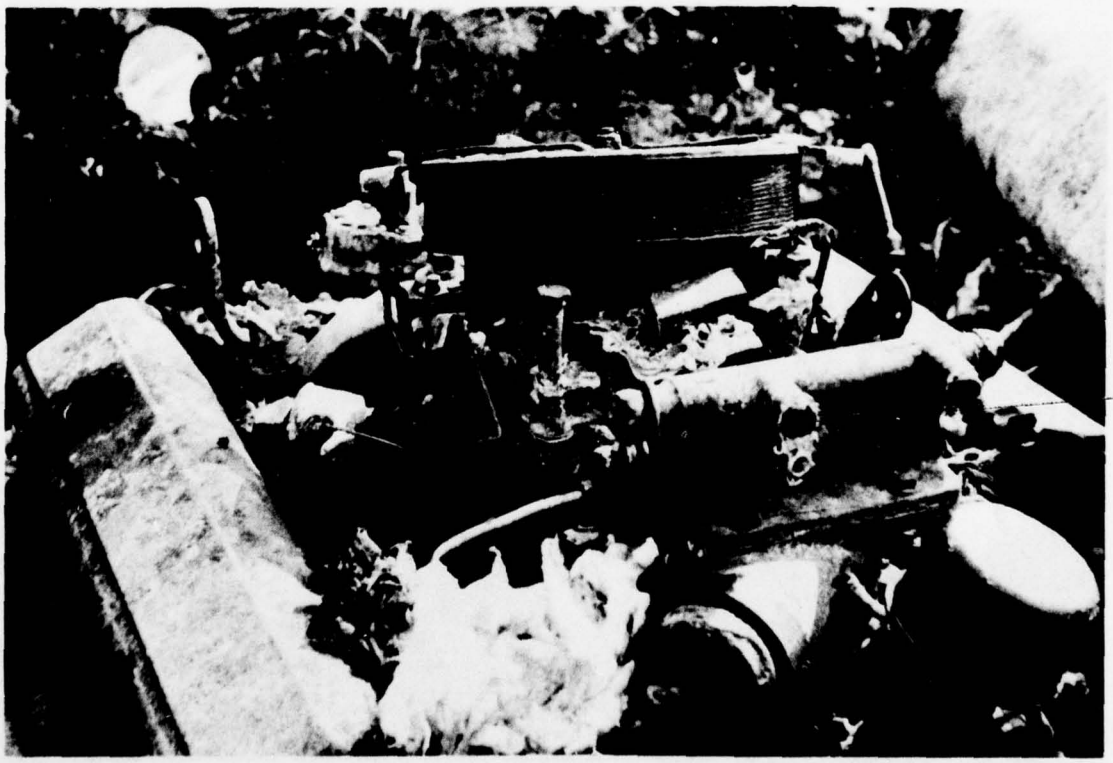


Figure 3 Carburetor and Flame Arrestor

Figure 4 Fuel Pump With Feed Line and Line To Carburetor Showing

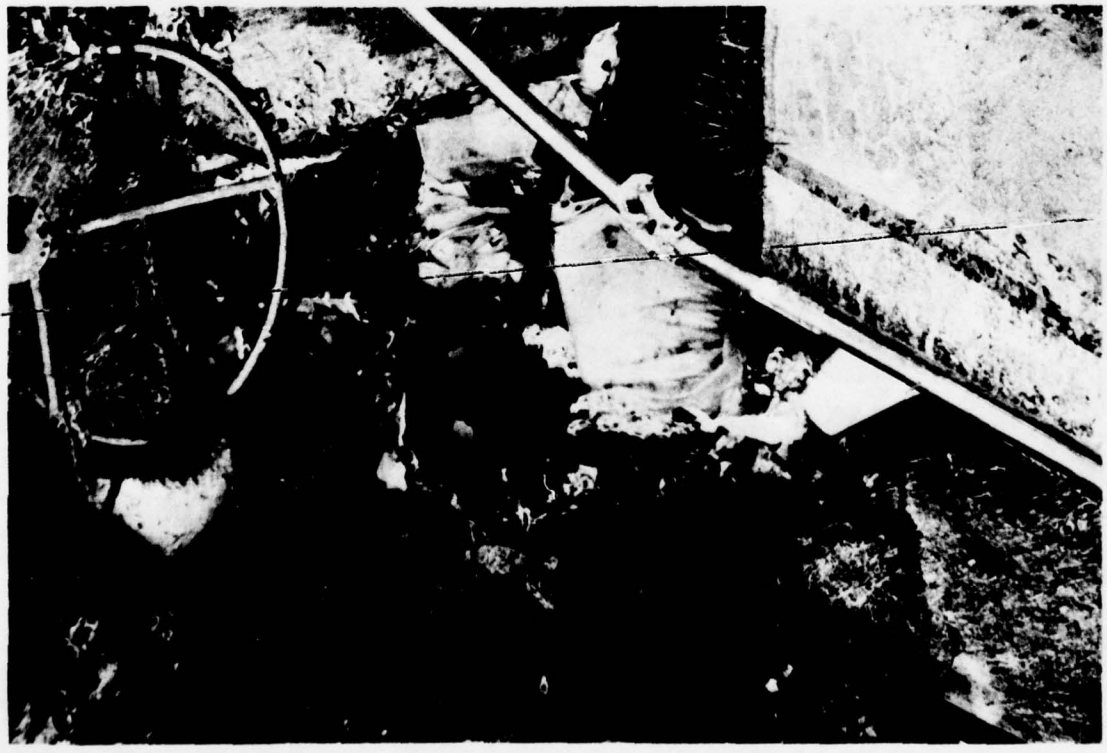


Figure 5 10 lb Fire Extinguisher And Remains Of PFD

Figure 6 Aft End Of Gas Tank Showing Siphon Tank Fitting, Shut Off Valve, And Copper Tubing

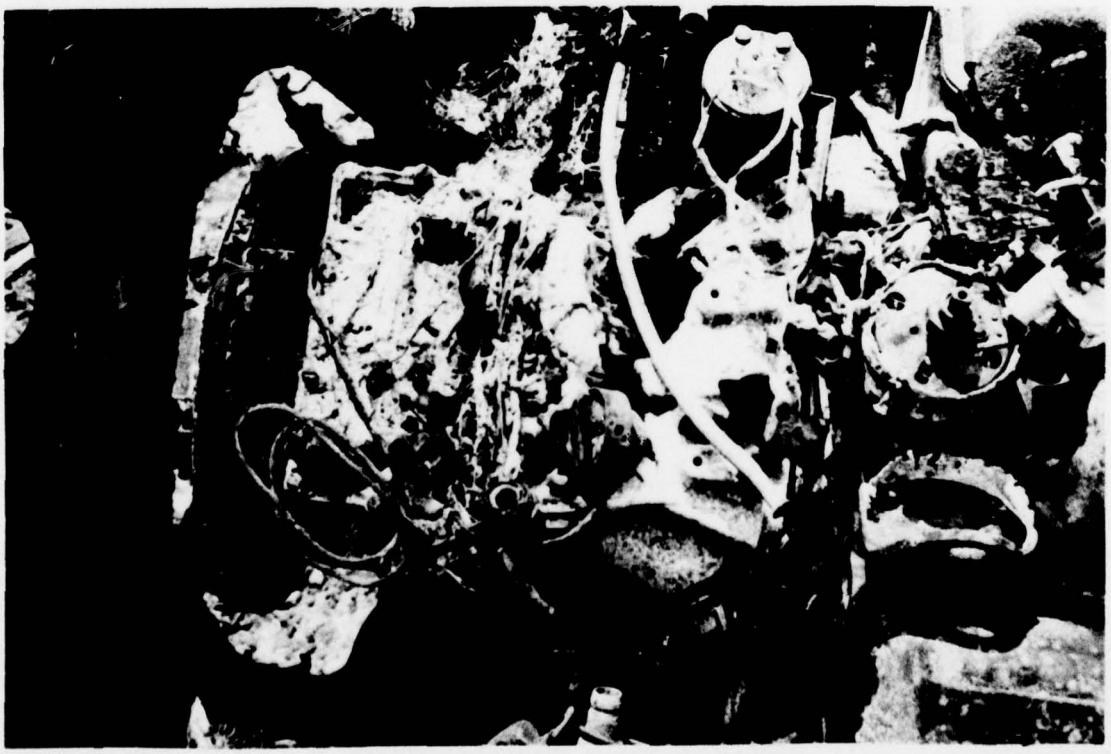


Figure 7 Aft End Of Engine Showing Melted Bell Housing

APPENDIX B

ACCIDENT INVESTIGATION REPORT

Date Of Investigation: Early October 1975

Date Of Accident: Late September 1975

Investigation: Fire/Explosion No. 75-02

SUMMARY — WYLE ACCIDENT NO. 75-674

A man and his 20 year old son left for an offshore fishing trip at about 0800. Reaching their destination an hour later, they idled the engines to rig the lines. After rigging, the son stood in the door leading to the salon just forward of the aft deck fighting chair. His father, driving the boat from the flying bridge, heard and felt an explosion. He looked aft to see his son with his clothes on fire on his hands and knees inside the cockpit.

After several attempts, the son managed to jump into the water. The owner shut down the engines and generator and grabbed two PFDs from a seat locker. He held onto the PFDs as he climbed over the front of the flying bridge and slid down onto the forward cabin top where a dinghy was stored. His intent was to unleash the dinghy and push it overboard. Although the small boat was secured to the cabin top with shock cords and a line with a slip knot, the owner found that he could not unhook the shock cords or release the slip knot, so he abandoned the idea of using the dinghy as a lifeboat. He walked aft into the cockpit and saw quite a bit of smoke rising into the salon from the engine room. Still holding the PFDs he went forward again without pulling the handle on the CO_2 fire extinguishing system

located in the cockpit, and again tried to unhook the dinghy. He couldn't. He jumped overboard with the two PFDs, put one on his son, and held the other under his arms.

The boat continued to burn and drifted away from them. Thirty minutes later, a boat came along, circled their burning boat and left. The owner was waving his PFD to attract attention, but because the boat had drifted approximately .375 to .50 of a mile (.60 to .80 km) away and the seas were running three ft (.91 m), he wasn't seen. Luckily, the operator of the other boat considered that survivors in the water could be some distance from the burning vessel, and came back and circled the boat. The survivors were found, picked up, and immediately transported to the hospital.

The owner's son was burned quite seriously. The owner received minor burns on his arms. The boat burned to the waterline and sank.

1.0 BOAT OCCUPANT DATA

Occupant	Age	Sex	Swimming Ability	Boating Experience	Formal Boating Instruction	PFD's Worn
Operator	40	M	Fair	>500 hrs	C.G. Aux.	No
Passenger	20	M	Fair	Very little	none	No

The owner of the boat had previously owned some eighteen power boats. He enjoyed fishing and cruising with his family and friends and thought of himself as being very safety conscious. He bought the boat almost a year ago and had had the engines and AC generator rebuilt by the service department of the automobile dealership of which he was sales manager. He had taken the basic Coast Guard Auxiliary course as well as a couple of their more specialized courses. His son had not done much boating. Apparently, he was away from home most of the time and had not participated in the family's boating activities.

2.0 ENVIRONMENT

According to the local weather bureau, the temperature on the morning of the accident was in the low 70°F (21° C) range. It was partly cloudy, and the wind was out of the north, northwest at 4-7 mph (6.44 - 11.27 kph). The owner agreed, but thought the wind was out of the northeast at a force of 5-15 mph (8.05 - 24.14 kph). He said there was a 2-3 ft (.61 - .91 m) sea running as a result of hurricane Eloise that passed offshore during the previous week.

3.0 NARRATIVE OF ACCIDENT

The following account of the accident was derived from an interview with the boat owner and telephone interviews with the Coast Guard MSO and the officer responsible for the SAR mission.

3.1 Background

The owner/operator of the subject vessel had bought his 36 ft (10.97 m) twin engine 1966 cruiser about one year prior to the accident. Although the boat appeared to run properly, he wanted to be certain that its propulsion systems were in perfect condition, so he had the two engines plus the AC generator removed and delivered to the service department of the automobile agency of which he was sales manager. The engines were torn down, checked, and repaired where necessary. The carburetors were replaced. After reassembly, the engines were painted and further protected from rusting by coating them with Texaco rust proofing. The owner had used this material on the underbodies of his cars with very good results. However, in this case, he found that the rust proofing tended to melt when the engines heated up. The oily substance would then puddle in the low spots on the engine and drip into the bilge. He noted that he should have cleaned it up, but hadn't gotten around to it.

The port engine had leaked oil constantly since it had been rebuilt. The owner had removed it and taken it back to the shop where the manifold gaskets were replaced. It still leaked. The owner then jacked it up without removing it from the bilge, dropped the pan and installed a new rear main bearing seal. It still leaked. Two weeks prior to the accident, the owner and his wife took a 200 mile (354.06 km) trip in the boat. The engine leaked a total of six quarts (5.68 l) of oil into the bilge during the trip. The port shaft packing gland also leaked, so there was an accumulation of bilge water in the boat for the oil to float on. Since the bilge pump was forward and the water accumulated aft while underway, the bilge area of the boat was liberally covered with a scum of oil.

He had been having constant problems with the on board AC generator. It was the type that was supposed to turn on when it sensed a demand. However, that portion of the control circuitry hadn't worked for quite some time. He had had it serviced recently, but it still wouldn't turn itself on when a piece of equipment on board called for power. Because of this, he left the generator on continuously while the boat was away from the dock. In this way, he knew that the contents of the refrigerator would not spoil.

He had noted that the exhaust riser on the generator would become red hot and stay that way when the generator was running constantly. He called the generator service people and found that that situation was "very unusual." He did nothing about it.

He had other electrical problems. For the last two months, his port batteries had to be refilled with water after each day's run. He had noticed a white smoke around the batteries after running the engine for some time. He would fill the batteries prior to attempting to restart the engines; however, they would generally be dead. Therefore, he usually had to use jumper cables to start the port engine from the starboard engine batteries.

When asked what changes he had made in the fuel or electrical system when doing the overhaul, he mentioned that he had replaced the copper fuel line from the fuel pump to the carburetor with an automotive quality non-reinforced rubber tubing. When asked why, he claimed that he didn't think that the copper tubing was in good shape; therefore, he replaced it.

Flammables were stored in the bilge, including a case of oil, several pressure cans of WD-40, paint in both spray cans and regular cans, and several cans of the Texaco rust proofing material.

The boat was equipped with a CO_2 fire extinguishing system that consisted of a large CO_2 tank in the bilge and a piping system that would carry the CO_2 to various nozzles at points along the pipe. The owner had noticed that there was a strange looking fitting on the pipe adjacent to the tank with a threaded hole in it. He couldn't understand why it should have a hole in it, so he bought a pipe plug and threaded it into the hole. The system had never been checked or serviced.

About six months ago, one of his 125 gal. (473.18 l) model gas tanks sprung a leak in the area where a baffle had sprung loose. A lot of gas drained into the bilge. The leak was detected, and the remainder of the gas in the tank was pumped into the tank of another boat. The tank was located under the cockpit and would have required extensive disassembly of the aft portion of the boat for removal for proper repair. Therefore, the owner decided to put a fiberglass

patch on the outside of the tank. He checked the patch before each trip and claimed that it had never leaked. However, he mentioned that he hadn't checked it in a couple of weeks.

3.2 Pre-Accident

The boat had been gassed up two weeks before the accident. After filling the tanks, the owner noticed the smell of gas vapors in the cabin of the boat. He couldn't find any evidence of a leak, so he dismissed it as a freak occurrence. This was the last time that the fiberglass patch on the gas tank was checked. He ran the boat for a few hours that day. The following weekend, he used the boat for fishing and had to jump the batteries to start the port engine. He filled the batteries upon his return to the marina.

On the morning of the accident, he and his 20 year old son arose early and had breakfast. They arrived at the boat at about 0745. The port engine wouldn't start, so the owner put the jumper cables on the batteries and started the port engine from the starboard batteries. He didn't take the jumper cables off.

He started the AC generator and left it running. He noted that each tank was over half full and felt that he probably had almost 200 gal. (757.08 l) in his tanks (100 gal. (378.54 l) each).

The owner did have to enter the bilge to connect the jumper cables, but said that he didn't go down into the engine compartment to sniff for fumes. He had an electronic sniffer on board and relied on it to warn him of fumes. It always read zero or almost zero. He didn't know if it actually worked or not. He said that he ran the blower for a while prior to attempting to start the engines.

Aside from the dead battery problem, everything seemed normal. The owner and his son left the marina at about 0800 and headed out into the Gulf of Mexico, on plane at about 3200 rpm. Once into the Gulf, they ran into a 2-3 ft (.61-.91 m) chop. Since the wind was fairly light, they assumed that the chop was due to the hurricane that passed through the area a week before. They continued into the chop for about six miles (9.66 km) then decided to slow down and troll. The owner and his son descended from the flying bridge. The son went to the lower controls in

the salon and kept the boat headed in a straight line at idle speed as the owner prepared the baits and rigged the lines. Everything seemed normal. The owner finished his rigging, suggested that his son sit in the fighting chair located in the center of the aft cockpit, and went above to control the boat from the flying bridge controls. His son walked to the back of the salon and stood in the centrally located doorway that separated the salon from the aft cockpit.

3.3 Accident

The owner advanced the throttles slightly then felt and heard a "WHOOF." He looked down into the cockpit and saw his son on his hands and knees in the port aft corner of the cockpit desparately trying to climb out of the cockpit and get into the water. His clothes, a light-weight shirt and cut-offs, were on fire and his skin was charred. His son made it into the water over the port transom corner. The owner shut off the engines, grabbed two life jackets from a PFD locker on the flying bridge, climbed over the forward portion of the flying bridge and down into the forward cabin top where a dinghy was secured. His intentions were to toss the dinghy overboard for use as a life boat.

The dinghy was secured to a cradle on the cabin top with shock cords and one line with a slip knot on one end. The owner purposely secured it this way so it would be easy to release in an emergency. He found that he couldn't release either the shock cord or the slip knot.

The owner thought at this time that the fire wasn't serious, so he walked aft along the port side deck, past the salon and down into the cockpit. He saw fire and smoke billowing out of the cracks in the deck leading to the engine room. Heat and smoke were coming from the aft salon door and the cracked side windows. The actuating handle for the CO_2 fire extinguishing system was directly in front of him on the aft salon bulkhead, but he never thought of pulling it. Now, he considered that the fire was indeed serious enough to abandon ship. He went forward along the port side deck and once again tried to detach the dinghy.

in the meantime, his son was in the water without a PFD and was treading water. The wind blew the boat in a reverse direction so the young man floated forward along the port side of the boat and by this time was off of the port bow. He was hollering at his father to get off of the boat. His father, still clinging to the two PFD's, went forward and jumped into the water off of the port bow. He joined his son and put a PFD on him. He didn't don his own

PFD. Instead, he manipulated it under his chest and armpits so it kept his head out of the water when he leaned forward. He told his son to swim away from the boat no matter how much it hurt. He was afraid of an explosion at this point.

3.4 Post Accident

The boat didn't explode, instead the fire slowly spread to the salon area above the engine room, then forward into the galley and sleeping areas, and aft to the cockpit area. Fire rose up through a control duct to the flying bridge. At one point, there was a lone ball of fire rising from the depth recorder, which sat generally on top of the control duct. The smoke became heavy and black. Someone on shore saw the smoke and called the Coast Guard. A helicopter and a fire fighting vessel were dispatched.

There were no other boats in the area. The two drifted away from the burning vessel. They were in the water for about 30 minutes and were about .375 of a mile (.60 km) from their boat when they saw a runabout heading towards their boat. It circled the boat and left. The owner waved his PFD in the air to no avail. The occupants of the runabout didn't see it. The boat disappeared, then in a few minutes reappeared. This time it circled the burning boat but was much farther away from it. Actually, the runabout driver saw no one on board when he ventured close to the stricken craft. He considered leaving the scene, then thought that there might be people in the water, but they could have drifted away from their boat. He came back and decided to circle the boat in ever increasing circles. The owner waved his PFD as the boat approached him and was seen. The son was pulled aboard first and was placed on the floor, aft. He wouldn't let anyone touch him and only wanted to be taken to the hospital as quickly as possible.

The son's injuries were mainly to the back of his legs, arms, and head, although the rest of his back was burned from the burning clothes. The skin was blistered on his arms and head, but had for the most part fallen off his legs.

The owner had received minor burns at a time unknown to him. The probability exists that he was burned from the heat escaping from the cabin side windows as he made his way past them.

The rescue boat took both victims to shore. An ambulance was called, and they were taken to the hospital.

Meanwhile, the Coast Guard helicopter arrived, saw no sign of life on board or in the water, and left. The Coast Guard fire fighting vessel arrived and extinguished the fire with foam. The boat had burned almost to the waterline. It sunk within 15 minutes of the arrival of the Coast Guard vessel. A water tank floated and was picked up by the Coast Guard. A fuel tank floated and was picked up by a commercial fishing boat that came on the scene at about the same time that the Coast Guard arrived. Reports indicate that the tank was ruptured. The captain of the fishing boat told the Coast Guard that it was bluish in color and was "blown out." He saw no use in keeping it, so he sunk it over a man-made reef in the Gulf.

4.0 FACTS FROM THE BOAT INSPECTION

The boat was a 1966 36 ft (10.97 m) Pearson. The fiberglass hull was of a semi-V configuration. The craft was powered by twin 1966 290 hp Chrysler inboard/outdrive engines.

The boat sank, so there was no boat inspection. Figures 1 and 2 show photos taken from a 1965 magazine showing a boat of the same make and model underway. The major difference between this boat and the sunken vessel is the addition of a dinghy on a cradle on the forward cabin top.

5.0 PSYCHOLOGICAL AND HUMAN FACTORS

The owner thought of himself as a safety conscious person. He wanted his boat to be in perfect condition; therefore, he had the engines and AC generator rebuilt. However, it appears as if he made a series of errors that eventually led to the disaster.

1. He replaced the copper fuel pump to carburetor gas line with a non-reinforced rubber tube.
2. He painted the engines with a petroleum based automotive undercoating product that melted when the engines heated up and dripped into the bilge.

3. One of the engines constantly leaked oil which floated on the bilge water. A thin film of oil had been distributed all over the bilge area. He hadn't cleaned it up.

4. The AC generator exhaust riser constantly ran red hot. He ran it anyhow.

5. The generator's starting system was defective. He knew this, but ran it anyhow.

6. The charging system on the port engine was defective. The batteries were constantly being charged at what appears to be the alternator's highest charging rate, resulting in the boiling off of all the battery water within hours. He hadn't gotten around to getting it fixed.

7. The port engine wouldn't start, so a pair of clamp-on jumper cables were run between the starboard batteries and the port batteries to start the port engine. On the day of the accident, the jumper cables were not removed after startup.

8. The starboard gas tank had leaked and had been repaired with a fiberglass patch. He hadn't checked the patch in two weeks.

9. The CO_2 fire extinguishing system had been modified by the owner who admitted to not understanding the system. His modification just made sense to him.

10. The owner never sniffed the bilges before startup. He used an electronic sniffer which had never been tested.

11. Flammable liquids were stored in the bilge.

It is easy to identify the safety hazards that could have provided the source of ignition and fuel that led to the explosion after the explosion happened. However, the owner didn't consider that any individual problem was particularly unsafe. He had been trying to fix the oil leakage problem. He intended to do something about the battery problem. He had called the generator manufacturer about the red hot exhaust riser. They hadn't specifically cautioned him about a fire hazard. He intended to clean up the undercoating from the bilge. And he checked the fiberglass patch on the gas tank regularly. He thought he was doing everything possible to keep up with the problems that occur on an inboard cruiser.

It was interesting to note his actions after his son went overboard. He admitted to going into a state of shock and not using good judgment during the sequence of events that followed. He didn't know why he never thought to throw his son a PFD, or a bunch of PFDs immediately after his son hit the water. Neither does he know why he never pulled the CO_2 fire extinguishing system switch. He stood right in front of it, but the thought of using it never occurred to him. He was in such a state of shock that he couldn't unhook the dinghy even though the lashing system was specifically designed to be easy to release in an emergency. Finally, he said that he didn't know why he didn't put on his own PFD. He mentioned that it may have been because he was so worried about his son's well being.

It seems that the sight of his son on fire upset him to the point that his thinking and subsequent actions were irrational. It would seem that the following sequence of events should have taken place:

1. He should have thrown his son at least one PFD or preferably several PFDs immediately. They were stored right beside him on the bridge.
2. He should have pulled the CO_2 fire extinguishing system switch while the fire was confined to the bilge.
3. He should have called for help on his own radiotelephone.
4. If he had done these things and thrown his son a throwable PFD with a line attached, he could have been pulled aboard in a matter of minutes and rescued by Coast Guard helicopter.

While in the water, he was not afraid of drowning. He had just seen the movie "Jaws" and was afraid only of the sharks that could be attracted by his son's injuries.

6.0 PROBABLE CAUSE OF ACCIDENT

Fires need fuel and an ignition source. There were several of each in the bilge of this man's boat.

Ignition sources:

1. red hot exhaust riser on AC generator;
2. possibility of end of jumper cable coming loose in the choppy conditions and arcing against object with opposite polarity; and/or
3. any one of the exposed arcing electrical components including the automotive type alternators, and distributors.

Fuel sources:

1. The rubber tubing installed by the owner as a gas line from the fuel pump to the carburetor could have ruptured, causing gas to be sprayed into the bilge.
2. The fiberglass patch on the gas tank could have loosened, causing the tank to leak.
3. Engine oil was covering the entire bilge.
4. Melted rust proofing was on the engine and in the bilge.
5. Hydrogen gas was being pumped out of all batteries if the jumpers were still connected, or out of the port batteries if a jumper clamp had loosened.

Two distinct possibilities exist. The hydrogen gas which was lighter than the air in the bilge filled the upper portion of the engine room and was ignited by the red hot exhaust riser on the AC generator or by the open spark in the distributors or alternators. That would have caused the initial explosion which would have had to have been severe enough to be the source of ignition for the fire that followed. The reason that the bilge filled with hydrogen this time rather than at previous times may be because of the jumpers. Four batteries were being overcharged rather than two.

Gasoline could have leaked into the bilge from either the fiberglass patch or the rubber fuel lines, or for that matter, from any one of many other sources. Ignition could have been from arcing battery cable ends or open sparks in the alternators.

Because the initial fire was an explosion, it is felt that the oil or rust proofing was not the fuel for the initial explosion, but contributed by being the fuel for the secondary fire that resulted from the initial explosion.

7.0 DYNAMICS/ANALYSIS OF THE ACCIDENT

A time oriented reconstruction of the accident is as follows:

0800	Left Marina
0840	Reached fishing spot
0840	Rigged fishing lines
0845	Explosion
0850	Owner entered water
0856	Coast Guard received call
0910	Small boat circled stricken vessel
0915	Owner and son rescued
0926	C. G. helicopter arrived on scene
1005	C. G. rescue boat arrived on scene
1006	C. G. began to extinguish fire
1012	Boat sank
1020	C. G. recovered water tank
1040	C. G. departed scene

The explosion was described as a "whoof" by the owner. It wasn't severe enough to physically displace the cabin structure or even blow the hatches completely out of their proper place. It sounded to the investigator as if it were a typical low level gasoline explosion. The engine room vents are relatively small and are high on the cabin sides. The engine hatches weren't secured, but were held in place on the salon floor by gravity. They acted as pressure relief valves as they raised up and released the pressure into the salon. The windows in the salon were almost closed. The only opening in the salon was the door leading to the cockpit in which the son was standing. Therefore, most of the energy from the expanding gases was released through that opening, hence the reason for the severe injuries to the son of the owner.

Pressure relief valves somewhere in the engine room would have prevented the injury to the son. If we assume that the owner's irrational behavior after the accident was because of his son's injuries as opposed to the fire itself, he may have acted in a more rational manner and may have been able to put the fire out, thus saving his boat, had his son's injuries been prevented.

Figure 1. Forward Profile Of Boat

Figure 2. Aft Profile Of Boat

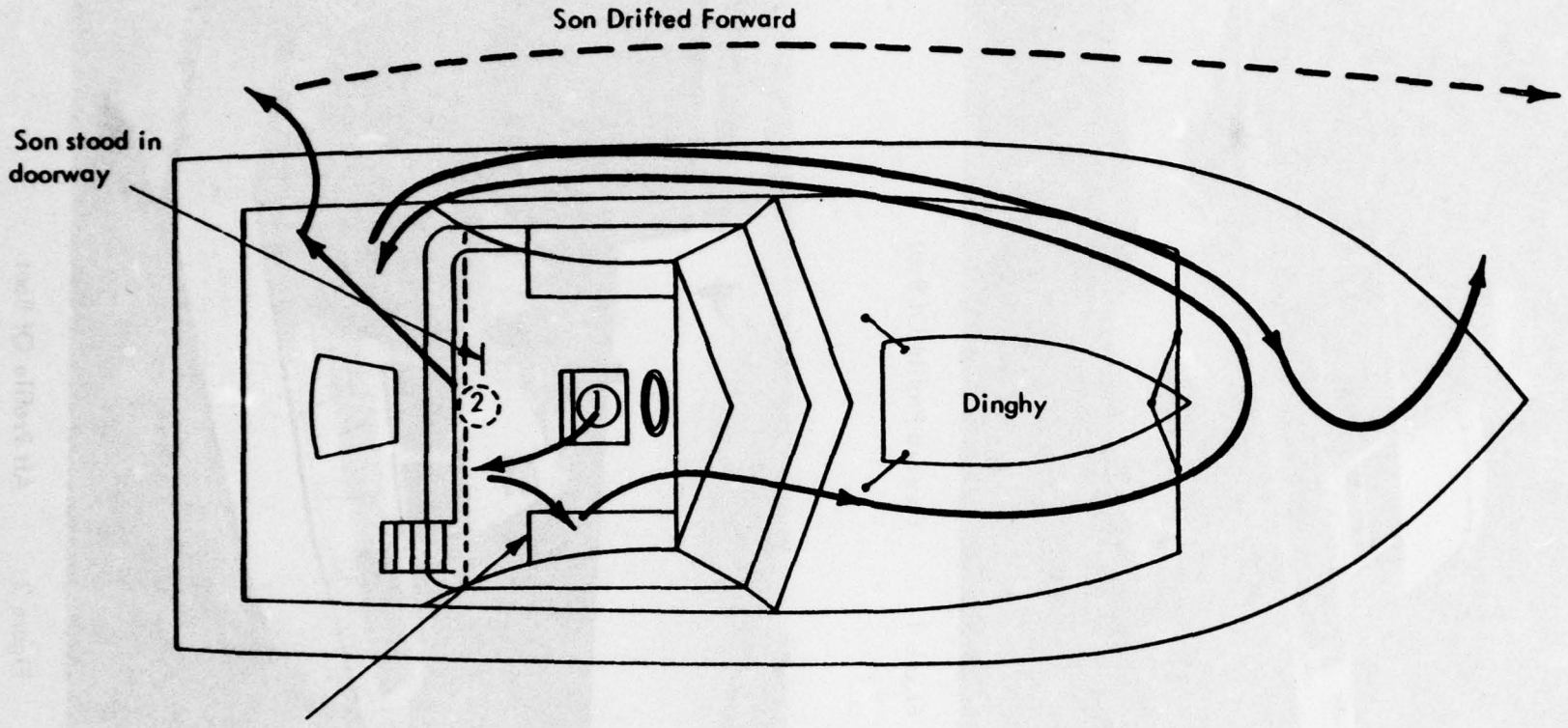


Figure 3. Plan View Of Boat

APPENDIX C

ACCIDENT INVESTIGATION REPORT

Date of Investigation: Early October 1975

Date of Accident: Late September 1975

Investigation: Fire/Explosion No. 75-03

SUMMARY — WYLE ACCIDENT NO. 75-663

The captain of a 58 ft (17.68 m) cruiser took his parents and friends for an afternoon boat ride. They cruised the inland waterway for about two hours, then entered the ocean for the return trip to their marina. Minutes later the captain smelled burning electric wire insulation. He immediately checked his ammeters and noticed that the starboard ammeter was filling with yellow smoke. At about that time the starboard engine stopped. His father took over the wheel while he went below to determine the extent of the problem. He opened the forward engine room hatch and saw open flames in the wiring behind the starboard engine. He felt sure that a short circuit was the cause of the fire and it was in the DC systems; therefore, he knew that he had to disconnect the batteries. He shut down the port engine and tried to radio for help. All three radiotelephones were dead. He entered the engine room and turned off the battery disconnect switches but noticed that the arcing continued. The shorting cables were on another circuit that was unfused and did not have a master disconnect switch. Because the batteries were located outboard of the engines and could not be reached, he couldn't disconnect the cables from the batteries.

All people on board donned PFDs. A boat came along and all POBs abandoned the burning vessel. Someone on shore saw the smoke and called the Coast Guard. They responded by sending a rescue boat to the scene. The fire was quenched, and the boat was towed ashore by the Coast Guard.

There were no injuries, but the boat suffered over $70,000 damage.

1.0 BOAT OCCUPANT DATA

Occupant	Sex	Age	Swimming Ability	Boating Experience	Formal Boating Instructions	PFD's Worn
Operator (1)	M	48	Fair	>500 hrs	Yes	No
Father (2)	M	73	Fair	>500 hrs	No	No
Mother (3)	F	70	Fair	>500 hrs	No	No
Friend (4)	M	55	Unknown	<100 hrs	No	No
Friend (5)	F	55	Unknown	<100 hrs	No	No
Sister (6)	F	46	Fair	<100 hrs	No	No

The operator of the boat had owned boats for 35 years. He had taken Coast Guard Auxilliary Courses and Power Squadron Courses also. Until three years ago, he had worked as an engineer for a manufacturing company. He enjoyed boats so much that he quit his engineering postion and got a job as captain of a yacht after obtaining his captain's license. This was the third boat that he had captained.

He had been in command of this boat for only two months. During that time, the boat was in use continuously, so he had not had a chance to do many of the maintenance and safety checks that he felt were important. He had made a list of some 40 items that needed attention in the near future, but had only been able to attend to a few of them prior to the accident. At least two items on that list were involved with the fire.

He was critical of the owner for not permitting him to thoroughly familiarize himself with the ship's systems during his first few months on board the boat.

He seemed to be conscientious and conservative in nature; not one to take chances with the safety of his boat or passengers.

2.0 ENVIRONMENT

The accident took place in South Florida on a beautiful afternoon. It was a clear day. The air temperature was about 85°F (32°C) with a 10 mph (16.09 kph) wind from the southeast. The sea had two ft (.61 m) swells with a wind created chop on top of the swells.

3.0 NARRATIVE OF ACCIDENT

The following description of the accident has been compiled from interviews with the captain of the subject boat, Coast Guard rescue personnel, and the electrical engineer for the manufacturer of the boat.

3.1 Background

The captain of the subject vessel had held his present job for only two months. Prior to that, he had been captain of a similar sized custom built fishing boat that is known as one of the area's finest and best maintained yachts.

He mentioned that he hadn't had time to familiarize himself with the many complicated systems on board the boat, because the owner had kept the boat going most of the time. He had found a problem with the electrolosis protection system and had solved the problem with the help of the electrical engineer at the yacht's manufacturing facility. The problem had not been noticed previously, because the boat had been kept in fresh water until recently.

He was concerned with the 12 volt DC systems. Both sets of batteries were 32 volts as were the starting and charging systems on the engines, the DC lighting, windshield wipers, blowers, pumps, etc. The manufacturer had provided a 12 volt DC power source for such items as radiotelephones, depth sounders, radars, stereos, etc. Twelve volts were tapped from the starboard bank of batteries. This was done through two eight-gage cables, extending from the batteries to a distribution panel in the salon. The negative cable was connected to the ground terminal on one of the four eight-volt batteries. The positive cable was connected to a screw that was tapped into the positive side of the sixth cell away from ground. The cables were unfused and were strapped within a bundle of cables routed along the hullside and leading to the salon.

Power was delivered to the radiotelephones and depth sounders through 14-gage conductors from the 30 amp fuses on the distribution panel. An additional 30 amp in-line fuse was located at the power entrance to each unit.

3.2 Pre-Accident

At 1500 on a beautiful, sunny day, the captain of a 58 ft (17.68 m) motor yacht took his parents, two of their friends and his sister for an afternoon boat ride. The boat was in a slip at a marina along the Intracoastal Waterway in South Florida. The captain's plans were to travel south, down the intracoastal waterway, past a nearby inlet that led to the ocean, and on to the next inlet, about 10 miles (16.09 km) distant. They were going to enter the ocean there, cruise north and rejoin the intracoastal waterway through the inlet that they passed on their way south. He estimated that they would have returned to the marina just before dark.

They cruised south, entered the ocean as planned, and turned north along the coast. The captain was at the helm in the deck house. The three ladies were sitting on a raised settee just behind the helmsman. The other two men were sitting on lounge chairs on the aft deck. The boat was about three miles (4.83 km) from the inlet and over a mile (1.61 km) from the shore when the captain decided to turn towards shore slightly. As he did, he turned on one depth sounder. It didn't work. He turned on the second depth sounder. The rotating disk holding the flashing light that indicates the depth turned very slowly. Just then, the captain smelled what he thought was burning insulation on electric wires. He looked down at the ammeters located on the control console to see if they were indicating either an overcharge or discharge condition. The starboard ammeter was filling up with a yellow gas.

3.3 Accident

At that point, the starboard engine stopped running. The port engine continued to operate. The captain called his father in from the aft deck and asked him to take over the helm while he went below to find out what had happened. The captain descended into the salon where the smell of burning insulation and smoke was more intense. He passed through the salon and went down another set of steps into the galley. The steps hinged up and formed the only readily available access into the engine room. The captain lifted the steps, looked into the

engine room and saw severe arcing along the cable bundle outboard and aft of the starboard engine. He also noticed open flames behind the starboard gear box. One of the two on board AC generators had been running. He noticed that it was no longer running and assumed that it had stopped at the same time as the starboard engine stopped.

The engine room was equipped with four portholes located on the hullsides about three ft (.91 m) above the waterline. These had been open throughout the trip. The captain closed them only during rough passages.

The captain lowered the galley-to-salon steps and went aft to the deckhouse to radio for assistance. All three radio telephones were dead. They were all powered from the starboard batteries. The captain was now sure that a short circuit existed in the primary power feeds to the 12 volt DC systems. He didn't know if the main DC disconnect switches located in the middle of the engine room would cut the power to those cables, but he felt that he had to find out. He pulled the handle to activate the automatic CO_2 fire extinguishing system. This was done just to make sure that the system had been activated. He felt that the starboard engine had quit as a result of the CO_2 system going off. He didn't know why the port engine had continued to run.

The captain told his father to head the boat for shore, while he went below to shut off the starboard master battery switch. If the 12 volt DC circuit was routed through this switch, opening the circuit would eliminate the arcing. Any remaining fires could be extinguished using one or more of the three hand fire extinguishers on board. The captain gathered all three extinguishers and placed them on the galley floor. He opened the stair/hatch, secured it, and went into the engine room after taking a deep breath. He took one extinguisher with him and sprayed the area in front of him as he proceeded aft between the two AC generators. He noticed that the arcing had decreased since the first time he looked into the engine room. He reached the switches and turned off the starboard switch. The arcing continued. He then knew that the 12 volt DC supply cables had not been routed through the switch. The alternator on the starboard engine was discolored. According to him, it looked "bad." A quick glance around the engine room before he left revealed at least a dozen places where arcing was occurring. He knew he had to disconnect those batteries. He exited the engine room,

lowered the steps, and ascended into the deck house again. He shut down the port engine, tried the radios again, although he knew this was wasted energy, and went back down to once again enter the engine room. This time his chore was going to be to remove the cables from the starboard batteries.

He opened the stair/hatch from the galley into the engine room for the third time. A blast of heat came out of the opening. He couldn't see into the engine room, because it was filled with smoke. He knew that he could not fight the fire any more. He lowered the stairs, and once again went above to the deckhouse where he explained the situation to his guests.

He knew that they were in no immediate danger. The boat would not explode since there was no gasoline on board. They were only about a mile off shore. Someone on shore would see the smoke and call the Coast Guard. He was sure of this. He showed his guests where the PFDs were stored, and asked them each to don one and adjust it to fit snugly. Each person in turn took one of the more than twenty, Type I PFDs stored under the raised settee in the deckhouse and put it on. The male guest started to climb overboard and was going to abandon ship. The captain persuaded him to stay on board.

He was in the process of thinking about lowering the 13 ft (3.96 m) Boston Whaler from its cradle on the aft deck hard top when he noticed a boat coming towards them from seaward. Other than this boat, there seemed to be no boat traffic visible. The boat, a 30 ft (9.14 m) sport fisherman, came alongside and its operator offered assistance. All persons climbed from the aft deck of the burning vessel to the forward deck of the fishing boat. At this point in time, the wind had pushed them to within .75 of a mile (1.21 km) of the beach. During the rescue attempt, the bow rail of the sport fisherman was damaged.

3.4 Post Accident

The operator of the fishing boat attempted to call the Coast Guard but found that his radio-telephone was also inoperative. The fishing boat owner wanted to leave the scene immediately and continue to port, but the captain persuaded him to remain on scene until the Coast Guard arrived.

The Coast Guard vessel arrived shortly. The captain was transferred to the Coast Guard vessel, and the fishing boat took the rest of the crew to port. At first, the fire was fought from the outside. Water was pumped into the engine room through the port holes and hull-side vents. The Coast Guard vessel did not have a portable pump on board with which to pump the water back out of the bilge of the burning boat, so they called for assistance.

Meanwhile, Coast Guard personnel went aboard and attempted to get to the engine room through the hatches over the engines. Unfortunately, the manufacturer of the yacht had not considered that this method of gaining access to the engine room would some day be used in an emergency, since the hatches located in the salon were covered with wall to wall carpeting, which in turn was covered with heavy furniture. The furniture was transferred to the aft deck and the carpet was cut away in the area of the hatches. Hatches were removed and more water was sprayed over the flames from above.

At this point, another Coast Guard vessel arrived with a portable pump. The burning vessel was now down by the bow and was some 50-70 yards (45.72-68.58 m) off the beach. The pump was put aboard and activated. A tow line was secured and the vessel was towed away from shore and anchored.

Coast Guard personnel continued to fight the fire. The batteries were still connected; therefore, arcing continued. They began to cut cables as a method of eliminating the short circuits. The captain said that he wanted to enter the boat to show them where to cut the cables adjacent to the batteries, which would have cut all power to those cables that were still arcing. Coast Guard officers would not let him reboard his boat. They felt that he would have only been a general hindrance. Coast Guard personnel felt that he was quite elderly, and thought that he had some sort of "condition." The coxswain mentioned that when they come on the scene, they take command. They want the people out of the way and out of danger. At that point in time, the Coast Guard is responsible for their safety.

The boat was towed to the Coast Guard station where the battery cables were finally cut, sometime after midnight. The seacocks were all closed to eliminate the possibility of the boat sinking at the Coast Guard dock and the boat was secured at 0230. The captain went home

to get some sleep after promising to get the boat towed off the Coast Guard premises at 0800. The boat was towed away before noon to a boat yard, where it is presently being stripped prior to major rework.

4.0 FACTS FROM THE BOAT INSPECTION

The 1968 boat was a 58 ft (17.68 m) aluminum Chris Craft cruiser with a 17 ft (5.18 m) beam. The vessel weighed 58,600 lbs (26,580.51 kg) with a draft of 3.67 ft (1.12 m). It was powered by two 12 cylinder GM diesel engines and had a 15 KW diesel powered AC generator and a 10 KW diesel powered AC generator. As is common with most vessels of this size and type, it was equipped with many luxury items such as stereos and television, radar, three radiotelephones, two depth sounders, air conditioning and heating separately controlled from all rooms, electrically operated anchor, search lights, docking lights, etc. A 13 ft (3.96 m) Boston Whaler was secured to the hard top over the aft deck and was removable with a small crane and electric winch.

At the time of the investigation, nothing in the engine room had been moved since the fire. A cable harness some six in. (15.24 cm) in diameter had fallen from somewhere along the hullside and lay on top of the starboard batteries, outboard of the engine. Insulation had been completely burned off. Only a bundle of copper remained.

The main engines still cranked and are salvageable as are the diesel engines powering the AC generators. The 32 volt battery system was interesting. It seems that the port bank of batteries are used only for starting the main engines (both of them). The starboard batteries are used only to power the accessories. Twelve volts is tapped off of the starboard batteries for the 12 volt accessories. The manufacturer installed a special rectifier/charger unit that was supposed to replace the energy consumed by the 12 volt accessories in that portion of the starboard 32 volt batteries. A 32 volt alternator on the starboard engine charged the starboard batteries also.

The system has since been changed. Current boats have only 12 volt systems. A special series/parallel circuit is energized by activating the starter switch that puts 24 VDC to the starters. All other DC systems are 12 volts. Therefore, special tapped circuits are unnecessary.

5.0 PSYCHOLOGICAL AND HUMAN FACTORS

It appears as if the captain's actions after the fire had started were quite rational. He localized the problem and did his best to eliminate the source of ignition. When he couldn't, he prepared his crew for abandoning ship in a relatively calm manner.

There seems to be some human factors problems with the boat. First, entry into the engine room is through the stairs from the salon to the galley. One must descend into the galley, then lift the stairs, which are hinged along the top edge, to an inverted position. A latch arrangement secures the stairs in that inverted position. An opening into the engine room is concealed behind the normal position of the stairs. The problem lies in the fact that the inverted stairs completely block one's exit from the galley to the salon. The stairs must be hinged back down prior to exit. Aside from being a nuisance, it is a safety hazard. If the steps had been up and a flash fire had occurred in the engine room, the captain may not have been able to reach the latch to lower the stairs to provide a means of escape to the salon and aft deck.

The second human factors problem was the location of the battery disconnect switches. They were located in the middle of the engine room, some eight feet from the entryway. They should be located in a more accessible spot, or be equipped with remote actuating mechanisms so that they can be turned off from the helm.

Third, all circuits, except certain safety related circuits, should have master cut off switches located as close to the battery as possible to minimize the amount of unswitched cable. Fuses or preferably circuit breakers should have been installed at or near the switches to protect the cables leading to the distribution panel.

Even if the captain could have entered the engine room for the third time, it is doubtful whether he could have reached the batteries to disconnect the cables. They were located outboard of the engines and directly under the large cable bundle that was arcing.

The fact that all three radiotelephones were powered from the same source when an alternate source could have been made available for one of the radios was a safety oversight on the manufacturer's part.

The captain considered using the 13 ft (3.96 m) runabout as a lifeboat. It is doubtful whether he could have lowered the boat and gotten all six people aboard. The stricken vessel was lying beam to the sea. The lifeboat when lowered would have banged rather violently against the hullside of the yacht. They would have had to set it adrift. The victims would have had to jump overboard, swim to the lifeboat, and climb into it. The four senior citizens on board may not have been able to accomplish that feat.

6.0 PROBABLE CAUSE OF ACCIDENT

The probability exists that insulation on the unfused 12 volt DC power feeds was worn off due to the cable rubbing against the exposed aluminum frames in the engine room. The cables were wrapped in a large bundle that was secured to the aluminum frames. The boat's motion would have imparted some movement of the cable bundle relative to the frames. The resultant abrasive action could have worn off the insulation. If the positive conductor contacted the frame, a short circuit would have occurred. Since the system was unfused, the cable would have heated, causing the insulation to melt. Insulation on other cables in the bundle would have melted causing more short circuits. The reaction would continue until the cables attached to the positive side of the batteries were disconnected.

This investigator hypothesizes that the insulation on the 12 VDC positive cable was almost worn through to the conductor at the start of the trip. The journey down the smooth inland waterway caused very little relative movement between the cable and the frame. It wasn't until the yacht left the inlet and ran generally abeam to a two ft (.61 m) swell that the abrasive action began. The remaining insulation was removed and the short circuit developed.

7.0 DYNAMICS/ANALYSIS OF THE ACCIDENT

The analysis of the accident has been covered in 6.0 above. A time history of events surrounding the accident follows:

1500	Left dock
1740	Proceeded out inlet
1747	Attempted to operate depth sounders
1750	Smelled insulation burning
1750	Noticed smoke in ammeter
1750	Starboard engine stopped
1751	Captain's father took over helm
1753	Captain looked into engine room - first time
1755	Captain tried to use radiotelephones for MAYDAY
1755	Someone on shore saw smoke and called Coast Guard
1758	Captain entered engine room - second time
1800	Captain turned off port engine
1802	Captain opened engine room hatch - third time
1805	Crew donned PFD's
1815	Rescue boat came in from seaward
1825	Crew boarded rescue boat
1835	Coast Guard arrived on scene
1845	Civilian rescue boat left scene
1845	Coast Guard began to fight fire
2400	Yacht secured to Coast Guard dock
0230	All fires quenched, seacocks closed, yacht secured
1200	Yacht towed off Coast Guard premises.

Pressure relief valves would not have had any effect on the fire itself, because an explosion never occurred. However, if the pressure relief hatches had been located in the hullside, the Coast Guard could have used the openings to insert the fire hoses. The fire may have been brought under control quicker. Damage may have been less.

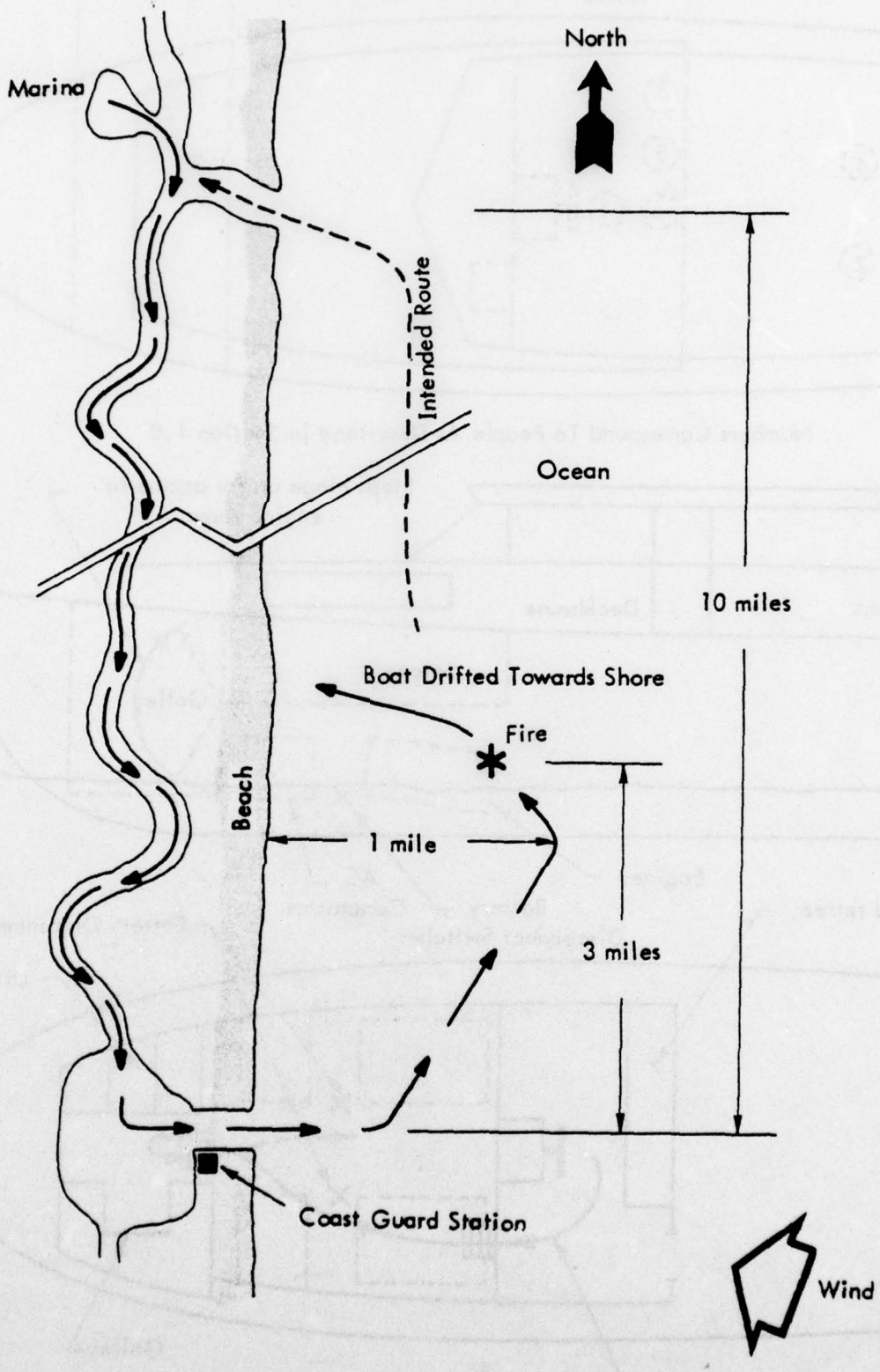
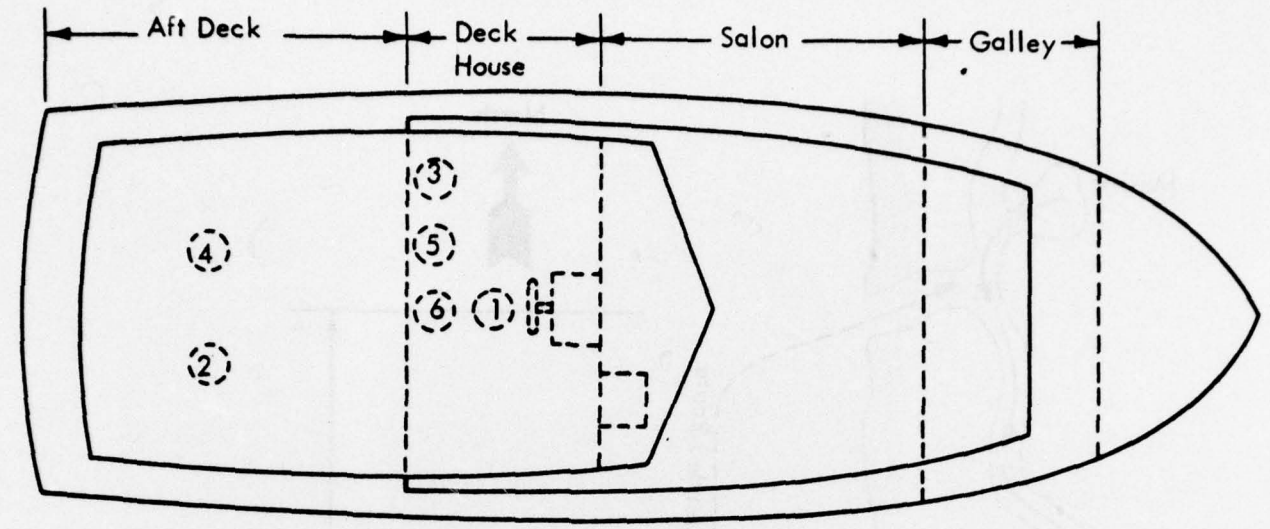


Figure 1. Accident Area Diagram



Numbers Correspond To People As Described In Section 1.0

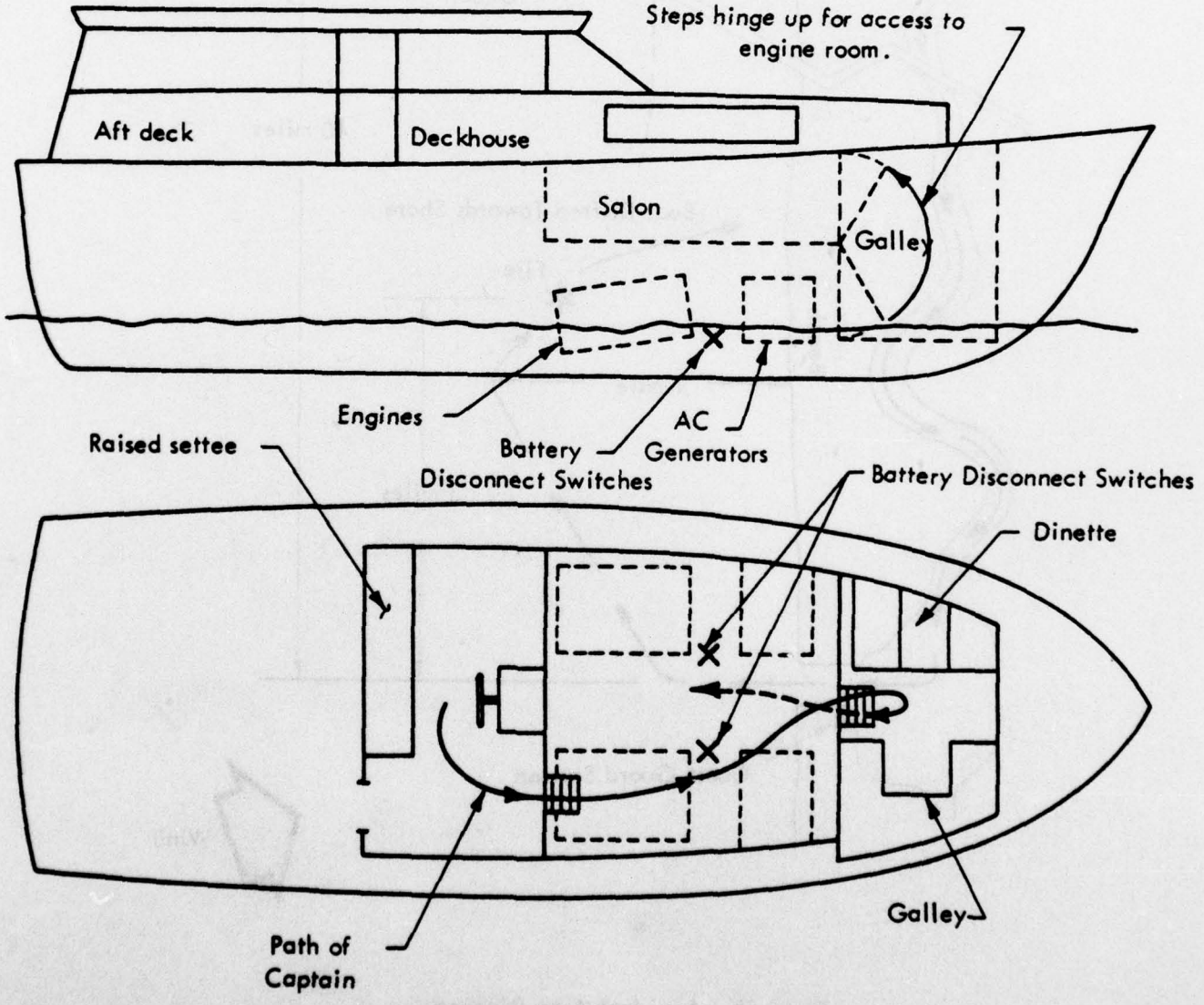


Figure 2. Yacht Plans And Profile

Figure 3. Port Profile

Figure 4. Starboard Profile

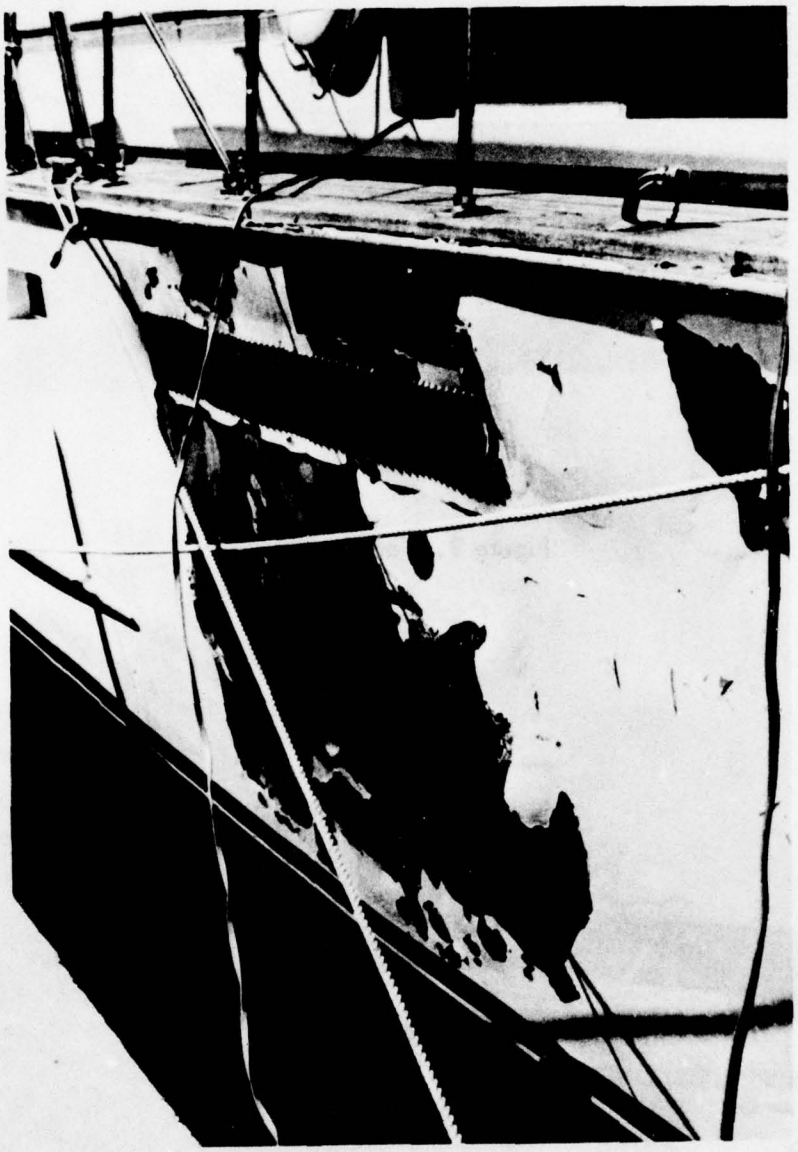


Figure 5. Exterior Damage - Starboard Hullside

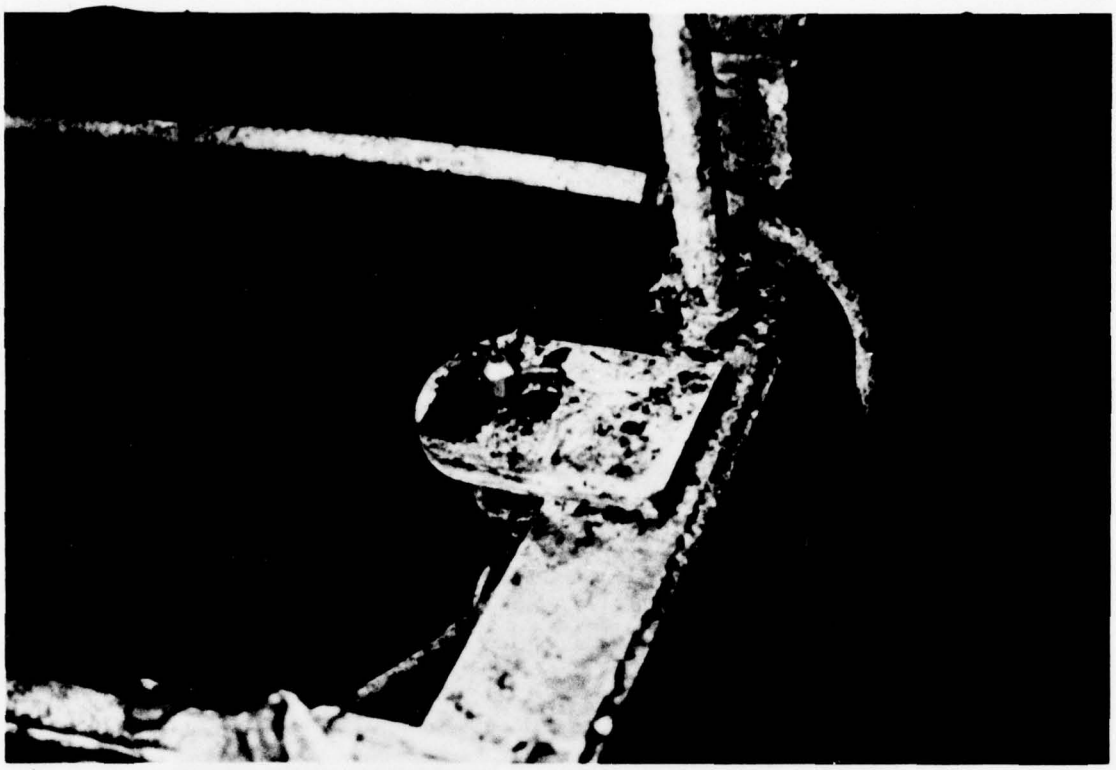


Figure 6. Battery Disconnect Switch

Figure 7. Salon, Showing Stair/Hatch Now Broken And Laying On Salon Floor

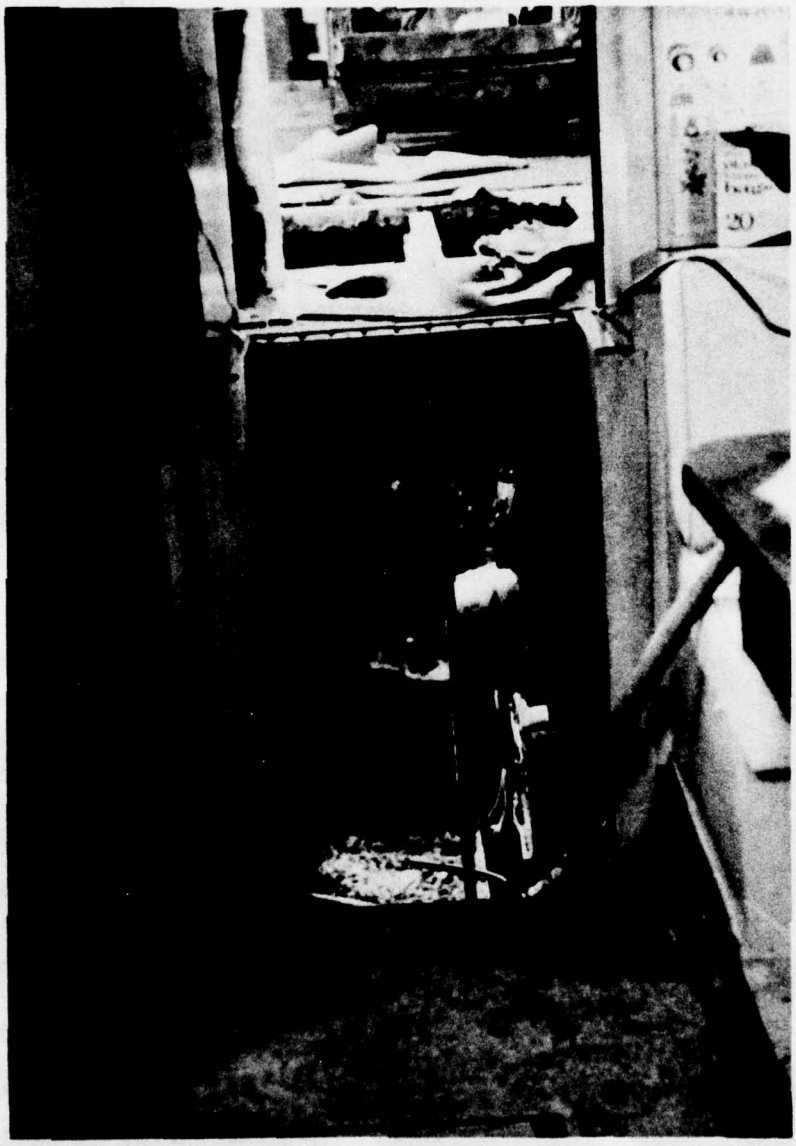


Figure 8. View From Galley, Aft Into Salon Above And Engine Room Below

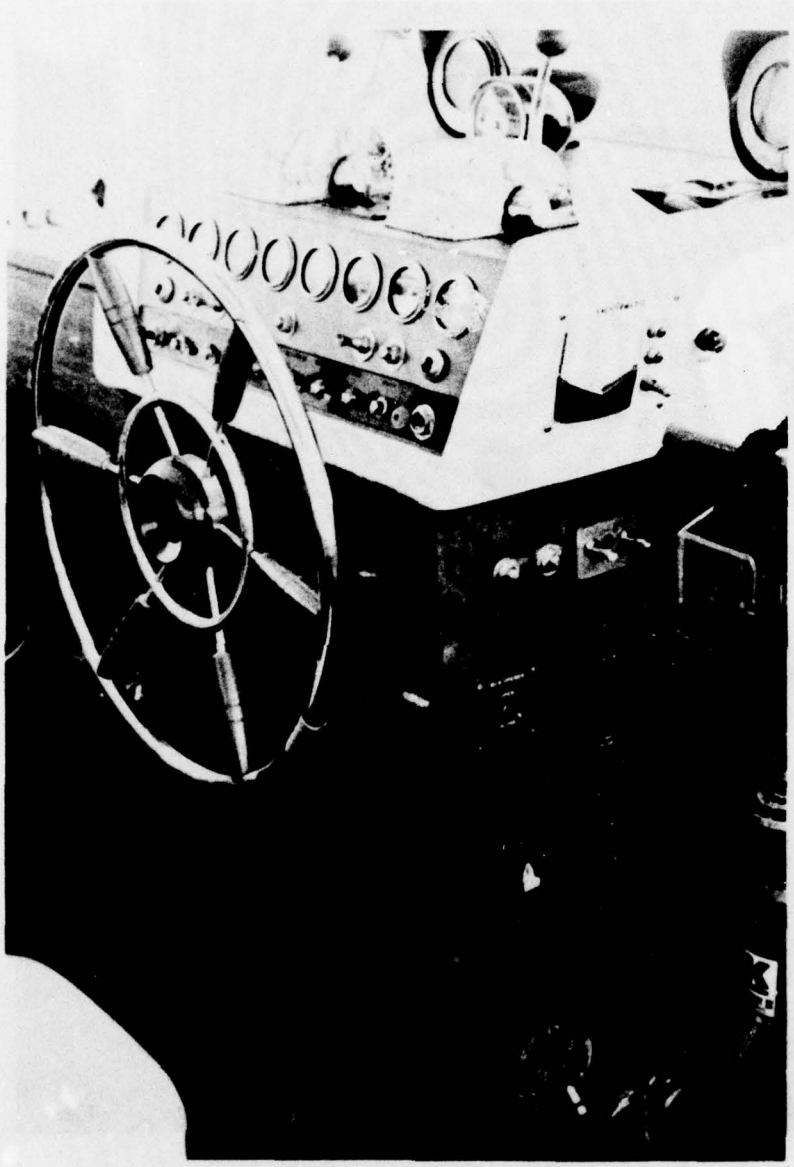


Figure 9. Control Console — Note Automatic Fire Extinguishing System Handle Pulled. (Bottom side of console) Ammeters Are Middle Two Gauges

Figure 10. Note Wire Bundle — Only Conductors Left

APPENDIX D

ACCIDENT INVESTIGATION REPORT

Date of Investigation: Mid-July, 1975

Date of Accident: Early July, 1975

Investigation: Fire/Explosion No. 75-04

SUMMARY — WYLE ACCIDENT NO. 75-338

The accident reported herein involved an 18 ft (5.49 m) inboard/outdrive, reportedly powered by a 165 hp engine. The type of accident was an explosion with a subsequent fire, which destroyed the boat beyond reasonable repair. There were no fatalities, but two of the nine people on board received severe burns.

At approximately 1230 on a morning in early July, 1975, two families, consisting of four adults and five children under 12 years of age, boarded the involved boat in preparation for an approximated 12 mile (19.31 km) trip to a picnic area located in northeastern Minnesota. The owner/operator started the engine and operated it at idle rpm for approximately 30 seconds. An adult male passenger stood on the dock holding the boat until the other passengers were aboard and until the operator started the motor. After the motor had been running approximately 30 seconds, the male passenger put one foot in the boat and started to push off from the dock with the other foot. At this point, there was a medium to high intensity explosion in the engine compartment. One adult female and one two year old child, who were seated in the stern starboard seat were ejected from the boat by the explosion. The other occupants

either climbed out of the boat onto the dock or jumped into the water. Two of the children received severe burns and one child received moderate burns as a result of the explosion. The boat fire subsequent to the explosion was extinguished in approximately 15 minutes after the explosion by a local fire department. The boat was declared a total loss.

1.0 BOAT OCCUPANT DATA

Occupants	Sex	Age	Weight	Swimming Ability	Boating Experience	Formal Boating Instructions	PFDs Worn
(1) Operator	M	30	235 lbs (106.59 kg)	Ex.	500 hrs	Power Sqd.	No
(2) Passenger	F	29	110 lbs (49.90 kg)	Ex.	500 hrs	Power Sqd.	No
(3) Passenger	F	2	25 lbs (11.34 kg)	None	---	---	No
(4) Passenger	F	2	25 lbs (11.34 kg)	None	---	---	No
(5) Passenger	M	5	50 lbs (22.68 kg)	Poor	---	---	No
(6) Passenger	F	24	110 lbs (49.90 kg)	None	None	None	No
(7) Passenger	M	24	200 lbs (90.72 kg)	Good	100 hrs	None	No
(8) Passenger	M	12	75 lbs (34.02 kg)	Good	None	None	No
(9) Passenger	F	1	20 lbs (9.07 kg)	None	---	---	No

1.1 Owner/Operator

It was apparent from the interview that the owner was an experienced boat operator (above average for his age). He had owned and operated various types of boats under 20 ft (6.10 m) in length for over twenty years. He had owned the involved boat for approximately one year. His formal education consisted of high school, and he seemed to be of above average intelligence and average physical condition. He worked as an insurance salesman for a national firm. He had completed the Power Squadron and Coast Guard Auxiliary boat operating courses and was a part-time swimming instructor in a local youth organization. From examination of structural modifications he had made on the involved boat prior to the accident, it was evident he was skillful with his hands and had an above average knowledge concerning boat construction.

1.2 Passenger No. 2 (Wife Of Operator/Owner)

She had completed the same boating courses as the operator, but it was evident from the interview that she was considerably less knowledgeable concerning boat operation and construction than the operator. Her formal education consisted of high school with several training courses in working with handicapped children. She worked at a local hospital as a child physical therapist.

1.3 Passenger 6 and 7 (Husband and Wife)

The male passenger seemed to have a fair knowledge concerning boat operation, but admittedly had very little experience in actual boat operation. He seemed to be of average intelligence and above average physical condition. The female passenger knew very little about boat operation and stated that she had no desire to learn. She could not recall any of the details concerning the accident after the explosion occurred.

1.4 Passengers 3,4,5,8 & 9 (Children)

These passengers were of normal intelligence and physical condition for their age.

2.0 ENVIRONMENT

The sky was clear and the visibility was excellent. The air temperature was estimated at 85°F (29°C) and the water was comfortably warm. The wind and water were calm. The water depth at the accident site was 4-5 ft (1.22-1.52 m).

3.0 NARRATIVE DESCRIPTION OF ACCIDENT

3.1 Pre-Accident

During the week prior to the accident, the owner, his wife, and a married couple who were friends of theirs made plans for a boat outing/picnic for early July, 1975. The party was to include the operator, his wife and three children, their friends, their child and their nephew.

On the night before the accident, the occupants received a normal night's sleep. They arose at approximately 0700 on a morning in early July, 1975, and started preparing for the trip. The friends arrived at the owner's home at approximately 0930. The women prepared the picnic supplies while the men loaded the boat and hooked the boat trailer to the owner's auto. The party left the owner's home at approximately 1100 for a launch ramp and dock area, approximately 15 miles (24.14 km) away. They stopped on the way and filled the boat fuel tank. The tank had an 18 gal. (68.14 l) capacity and the owner stated that he filled the tank to approximately the 17 gal. (64.35 l) level. He never filled the tank completely full, because he did not want the fuel to overflow or slosh out on the boat.

The party arrived at the launch ramp at approximately 1200. The boat battery was discharged, and the owner was aware of this fact. When they arrived at the ramp, the owner exchanged the boat battery for the one in his car. The boat motor cover was removed and the motor started and run for a short period of time with the boat on the trailer. Prior to starting the motor, the operator turned on the engine compartment blower and left it on after the motor was stopped. The boat was launched and the gear and picnic supplies loaded aboard. The operator stated that the engine compartment blower was on during the launch and until the explosion because the motor squeaked when running and he could hear the squeak. The operator and all the passengers got aboard except the adult male who was holding the boat alongside the dock.

3.2 Accident

Gear and people aboard were as shown in Figure 1, and the weather as in Section 2.0. The operator started the motor and noticed it was running rough. After approximately 15-20 seconds, the motor stopped. The operator got the motor started again after two or three attempts. The motor was running rough, but the operator felt it was not bad enough to delay the trip. After the motor ran for approximately 30 seconds, the male passenger put one foot over the port gunwale into the boat and started to push the boat out from the dock with the other foot. At this point, an explosion occurred in the engine compartment. Locations of the people aboard and their actions immediately after the explosion were as follow:

1) Operator/Owner — He was standing at the helm, facing the stern. The explosion propelled a section of the engine cover forward, hitting him in the face and chest. The impact threw him forward into the windshield, breaking the starboard windshield support. His location after the explosion was lying back across the windshield with his head and shoulders resting on the bow.

2) Female Passenger (Adult) — She was seated in the starboard stern seat, adjacent to the motor cover, holding female passenger No. 3. She was thrown aft over the transom and came to rest with her legs from the knees down inside the boat and the rest of her body hanging over the transom. A part of the motor cover or some other object was lying across her legs. She was able to kick the object off and slid head first into the water.

3) Female Passenger (Child) — She was sitting in the lap of passenger No. 2. She was blown over the transom into the water approximately 10 ft (3.05 m) from the boat.

4) Female Passenger (Child) — She was seated in an automobile "car seat" which had been installed on the top of the motor cover. She was apparently thrown straight up by the explosion and came to rest on the starboard side of the engine with her feet down in the motor well.

5) Male Passenger (Child) — He was seated in the stern seat, port side, adjacent to the motor cover. He remained in essentially the same location after the explosion.

6) Female Passenger (Adult) — She was standing amidships immediately behind the helm seat and the adjacent port side seat. The force of the explosion threw her forward between the seats to a face down position on the deck.

7) Male Passenger (Adult) — The force of the explosion blew him back on the dock to a sitting position a few feet from the boat.

8 & 9) Male and Female Passengers (Children) — The male passenger was seated in the port seat adjacent to the helm seat, holding No. 9. These occupants remained essentially in the same location after the explosion.

The motor cover and aft seats were either blown out of the boat or destroyed. The helm seat was blown over the starboard side, intact, approximately 25 ft (7.62 m) from the boat. Immediately after the explosion, the operator noticed that the engine compartment was on fire. The flame heights were extending a few feet above the gunwale and appeared to be more concentrated in the forward section of the motor well. He instructed the passengers that were still

in the boat to get out. Passenger No. 7 helped Nos. 6, 8 and 9 out of the boat onto the dock. The operator went aft and threw No. 5 over the stern into the water. No. 5 then swam a few yards to shore. During this time, No. 2 had climbed on the outdrive to look in the boat for No. 4, whom she located in the engine compartment. After No. 5 was thrown out, the operator returned to the helm position. The flames started spreading forward and the operator started to jump over the starboard side, thinking that everyone was out of the boat. At this time, No. 2 called to the operator, telling him that No. 4 was in the engine compartment, and she could not pull her out. The operator went astern, lifted No. 4 out of the motor compartment, and threw her over the stern into the arms of No. 2. No. 2 then walked ashore carrying No. 4. The operator jumped over the starboard side into the water, and walked ashore.

3.3 Post Accident

The flames spread rapidly forward, and within five minutes the entire boat was ablaze with flame heights of 15-20 ft (4.57-6.10 m). The fire department and an ambulance were called a short time after the explosion by a witness on shore. The ambulance was directed to the wrong location and the injured occupants were taken to a local hospital by private auto within 10 minutes after the explosion. The fire department arrived on the scene within 15 minutes after the explosion and extinguished the fire. Injuries sustained as a result of the explosion and subsequent fire were as follow:

Occupant No.	Injuries
1	Minor bruises on the face and chest.
2	Minor burns on left wrist and hair.
3	Second degree burns on left hand.
4	Third degree burns on top of feet and second degree burns on bottom of feet and left side of face. Occupant still hospitalized at time of investigation.
5	First degree burns on chin, neck, and toes on left foot, and burned hair.
6	Minor hair burns.

Occupant No. (con'd)	Injuries (con'd)
7	No injuries.
8	No injuries.
9	No injuries.

According to the occupants, the investigating officer and witnesses, none of the people aboard had been drinking on the day of the accident.

Refer to Photographs 1 and 2 for accident area.

4.0 FACTS FROM THE BOAT INSPECTION

The boat was a wooden 1967 model Thompson I/O and, according to the owner, had a "1974 model 165 hp Mercruiser engine." The overall length was 18.25 ft (15.56 m) with a maximum beam of 8 ft (2.44 m). "The engine had been installed by a Mercury dealer approximately one year prior to the accident." The owner estimated that he had put about 25 hrs on the engine.

The examination of the boat showed (see photographs) that the engine has two single barreled carburetors and that the fuel pump-to-carburetor line had been flexible line instead of metallic. Upon checking with Mercury (and repair manuals), it was found that Mercury had stopped using flexible line in 1969. Also, no 165 horsepower models (after 1969) had flexible fuel lines. In fact, the power plant was probably a 1966 or earlier and was also more than likely a 150 or 140 hp engine (which did come with twin carburetors).

The interior of the boat was completely gutted by the fire, except for the bow section, as shown in Photographs 3 through 10. The fuel tank was permanently installed in the approximate center of the bow section. The fuel filler hose ran from the top end of the tank approximately 18 in. (45.72 cm) up to a 45 degree angle to the filler cap located on the bow top, port side. The vent line ran from the top of the tank (opposite end to filler hose) to the starboard side vent fitting. A copper fuel supply line ran from the tank top along the port side, under the forward section of the engine to a flexible hose connection on the starboard side. A flexible hose connected the supply line to the fuel pump and a flexible line had connected the fuel pump to the

carburetors. Only charred pieces of the flexible fuel lines were found. The flame arrestors that had been on the carburetor appeared to be in good condition. The carburetors had been melted by the fire. The bow top was torn away from the stem and sides. This was probably done by the firemen to gain access to the forward part of the boat in extinguishing the fire. The engine compartment blower was of the squirrel cage design mounted high on the transom, starboard side. The blower had no inlet hose running to the bilge and the outlet was directly through a 3 in. (7.62 cm) hole in the transom. Approximately two weeks before the accident, the owner had completed modifications to the passenger compartment, which consisted of a new plywood deck, extending 4 in. (10.16 cm) higher than the original, and of fabricating a new motor cover. Prior to installing the deck, the entire bilge was cleaned and varnished.

5.0 PSYCHOLOGICAL AND HUMAN FACTORS

The operator seemed to be very safety conscious concerning the operation of his boat. On the day of the accident, he removed the engine cover prior to starting the engine to release any fuel vapors that could have been present. He started the engine compartment blower prior to starting and left it energized until the explosion occurred. He was familiar with I/O boats and was aware of the fact that explosions resulting from fuel vapors in the engine compartment had occurred on other boats. The fire extinguisher was stowed in the seat that was blown out of the boat; therefore, if he had decided to attempt to extinguish the fire, the extinguisher would not have been available.

The operator stated that he required the children to wear PFDs when underway, yet none of the occupants were wearing PFDs at the time of the accident. It is unknown if the operator intended to have the occupants, particularly children, put on the PFDs after clearing the dock and before getting underway.

The owner did not perform a close visual inspection of the engine compartment on the day of the accident. He stated that he had worked on the boat during the winter preceding the accident and was confident that the wiring, fuel lines, etc., were in good condition.

6.0 PROBABLE CAUSE OF ACCIDENT

The engine area was burned so badly that it was impossible to determine the exact cause of the fire, other than that it was fuel related. The copper feed line coming from the fuel tank was in good condition. The flexible feed line from the copper line to the fuel pump and the flexible line from the fuel pump output to the carburetors were completely destroyed by the fire. Since the engine was running at the time of the explosion, it is assumed that a leak developed between the fuel pump and the carburetors. With the engine running, it is unlikely that the input line to the fuel pump (suction line) would leak without causing the engine to stop from fuel starvation. The leak was probably at a location that allowed the fuel to contact the hot engine block which vaporized the fuel into an explosive mixture. The engine had not been running long enough to heat the engine compartment sufficiently to cause a high rate of fuel vaporization to an explosive mixture level. The source of ignition could not be determined.

The explosion was of medium to high intensity. The explosion may have been confined to the engine compartment had the engine cover been equipped with pressure relief valves. The resultant fire, if any, could have most likely been extinguished with the fire extinguisher on board. Also, had the exhaust blower been equipped with an inlet hose, extending to the lower part of the engine compartment to evacuate fuel vapors, it is doubtful if it would have been sufficient.

There is a possibility that the operator stepped on or otherwise loosened or ruptured a fuel line while installing the auto battery in the boat. The operator stated that he felt this possibility was remote due to the fuel line routing in the engine compartment.

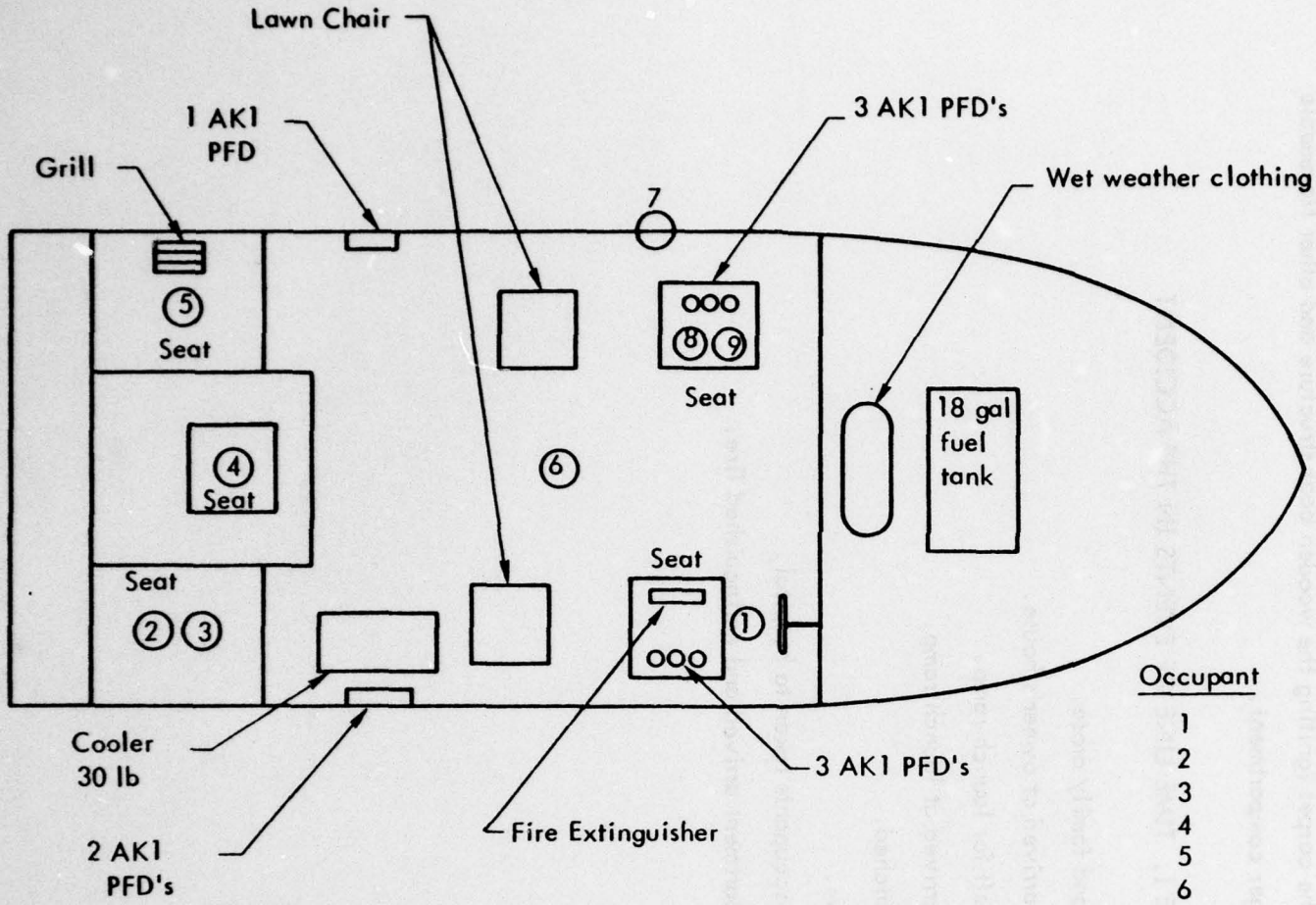
7.0 DYNAMICS/ANALYSIS OF THE ACCIDENT

The explosion blew the engine cover and aft seats away from the stern section, exposing the engine to the atmosphere which provided oxygen to sustain the fire. Immediately after the explosion, the fire was relatively small and was confined to the forward section of the engine, which indicated that only a small amount of fuel was present at this time. The intensity of the initial fire was sufficient to ignite the wooden boat structure around the engine well, ignite the carpet, and melt the flexible fuel line to the fuel pump input. When the fuel line melted,

raw fuel in the line to the fuel tank flowed to the fire area, which explains the high flames coming from the engine compartment within 2-3 minutes after the explosion. The fire then spread forward along the carpet igniting the wooden boat structure and other flammable material in the passenger compartment.

TABLE I. TIME LINE OF EVENTS IN THE ACCIDENT

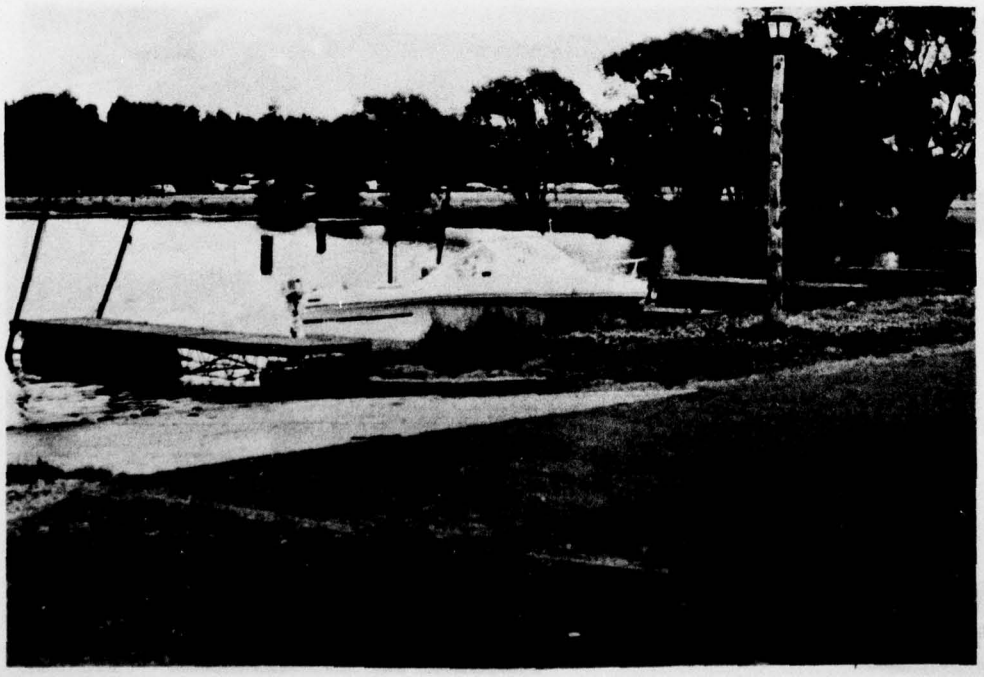
0700	Owner and family arose.
0930	Friends arrived at owner's house.
1100	Group left for launch ramp.
1200	Group arrived at launch ramp.
1220	Boat launched.
1230	Explosion.
1240	Injured occupants taken to hospital.
1245	Fire department arrived and extinguished fire.



Occupant	Weight
1	235
2	110
3	25
4	25
5	50
6	110
7	200
8	75
9	20

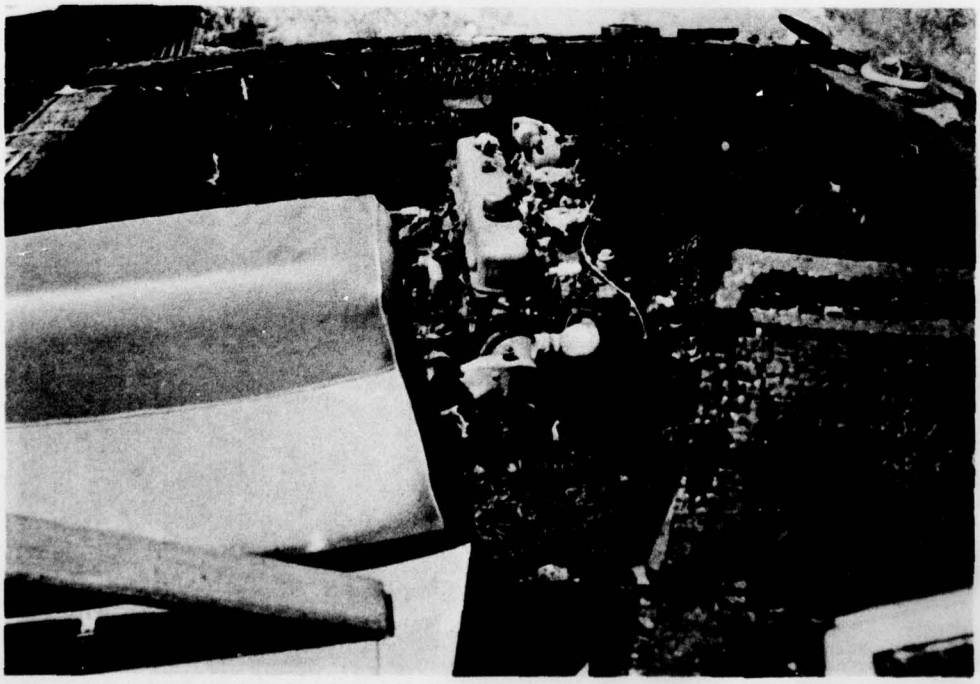
Figure 1. Boat Load Distribution At Time Of Accident

Photograph 1. Accident Area



Photograph 2. Accident Area

Photograph 3.



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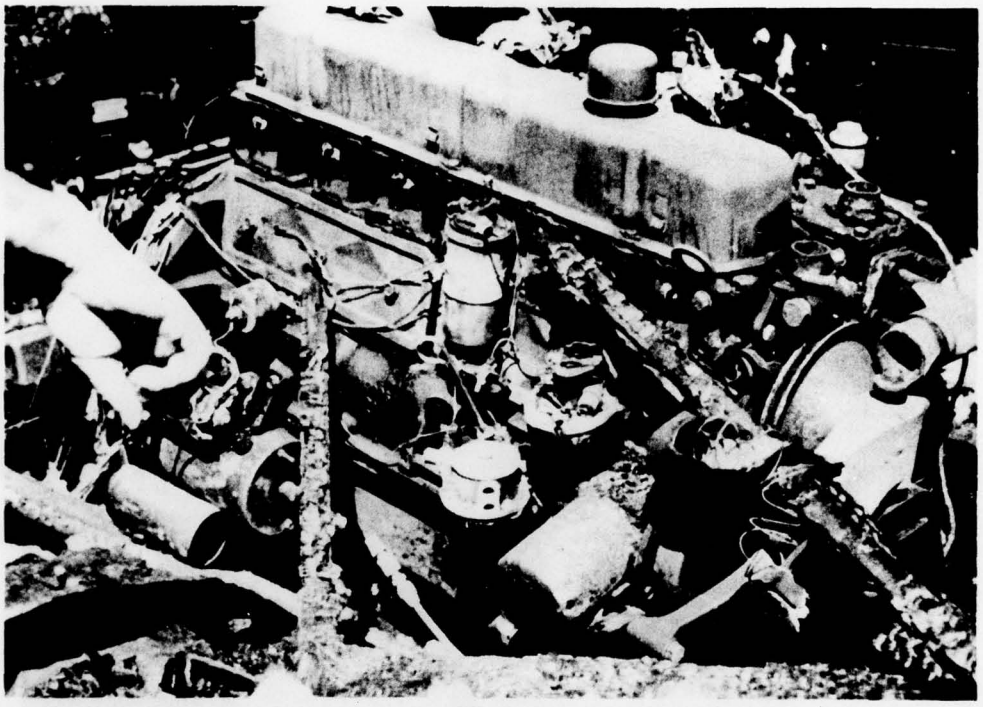

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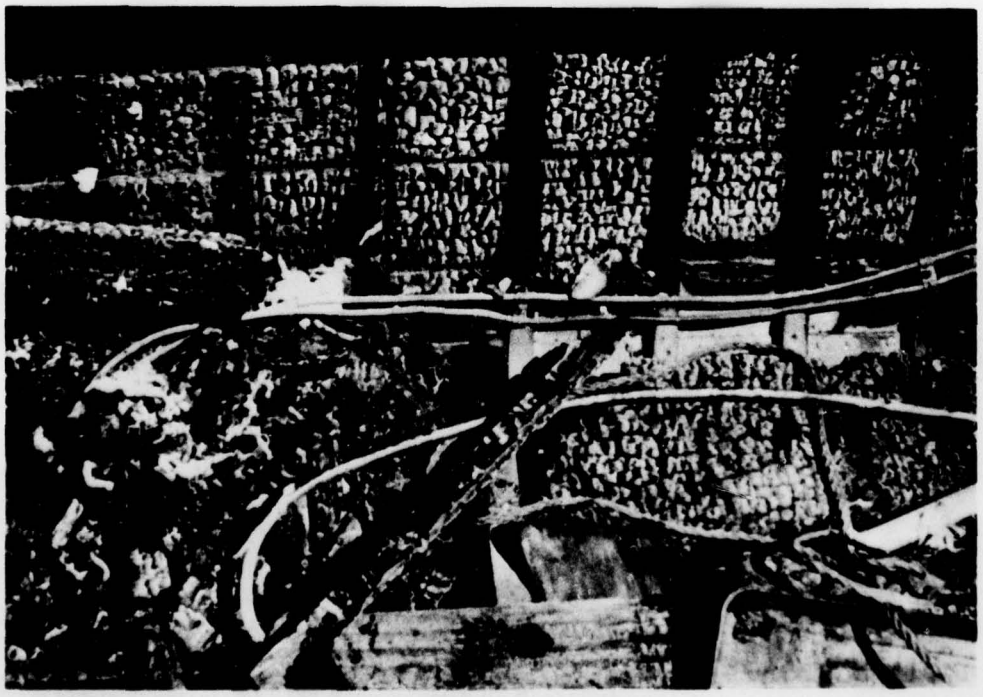
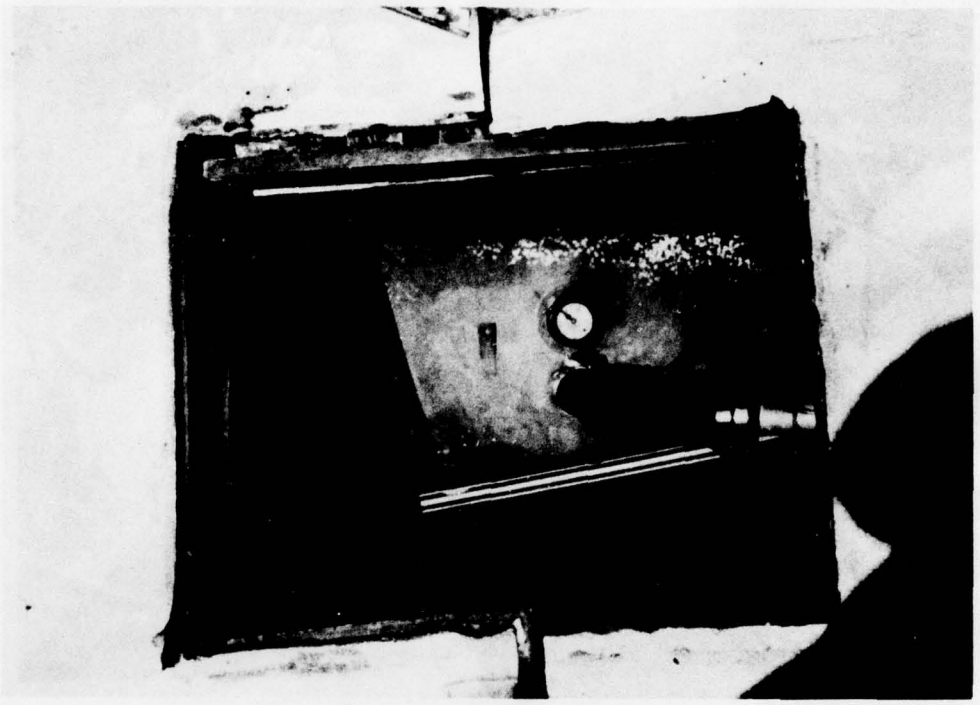
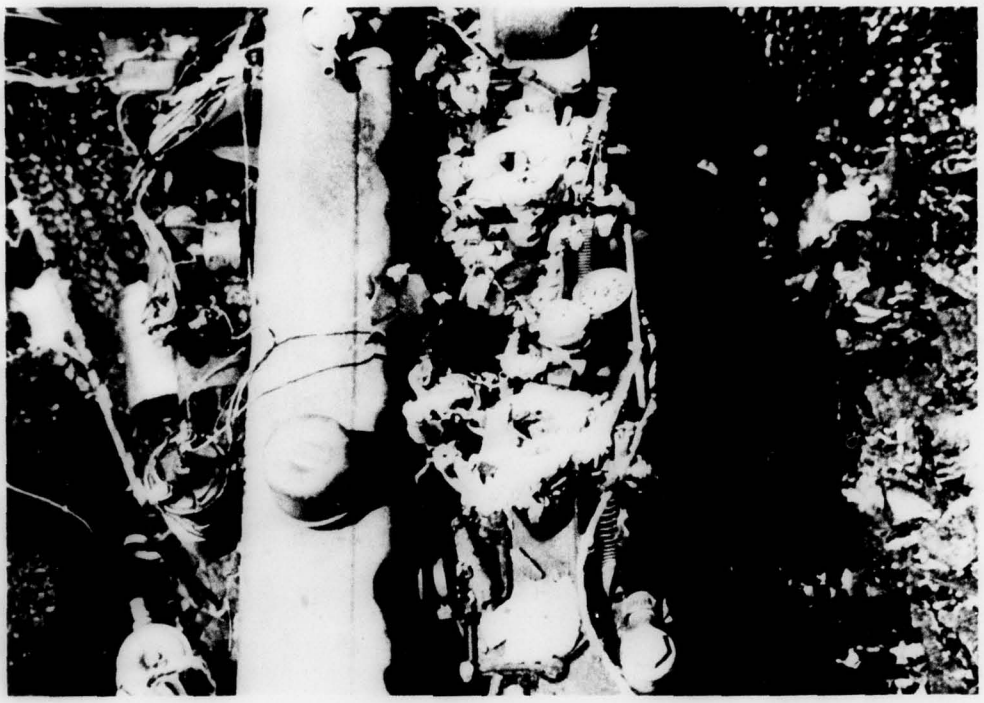


Photograph 6.



Photograph 7.

Photograph 8.



Photograph 9.

Photograph 10.

AD-A045 402 WYLE LABS HUNTSVILLE ALA F/G 13/10
ESTIMATE OF THE POTENTIAL BENEFIT OF THE PRESSURE RELIEF VENT/F--ETC(U)
JUN 77 C SAUTKULIS, J BOWMAN, B SMITH DOT-CG-40672-A
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2 OF 3
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APPENDIX E

ACCIDENT INVESTIGATION REPORT

Date of Investigation: July 21, 1975

Date of Accident: Early July, 1975

Investigation: Fire/Explosion No. 75-05

SUMMARY — WYLE ACCIDENT NO. 75-354

The accident reported herein involved a 28 ft wooden 1964 model Owens inboard cabin cruiser powered with a 1964 model 185 horsepower Chevrolet engine. The type of accident was an explosion and short duration flash fire, resulting in minor to severe injuries to the six occupants aboard. The boat was moderately damaged by the overpressure created by the explosion. Very little fire damage was evident.

At approximately 2030 in early July, 1975, six people (four adults and two teenagers) boarded the involved boat at a marina located in northern Michigan. The party was to participate in the annual blessing of the boats ceremony. Approximately one hour before the occupants boarded the boat, the operator and the teenage male passenger had fueled the boat, bringing the 50 gallon tank to approximately 1/2 full. During the fueling operation, the deck plates were removed and the engine compartment blower was running. After the occupants boarded, the operator started the engine in preparation for getting underway out of the harbor. There were 20 boats that were to participate in the blessing of the boats ceremony, and the involved boat was number 13. Approximately 15 minutes was required to get the boats in line to start the procession out of the harbor. The engine of the involved boat was running at idle speed

during this time. Immediately after passing the harbor breakwater, the operator increased the engine rpm from 450 to 500 at which time the engine stopped. The operator restarted the engine and proceeded straight ahead at 500 rpm. After approximately five minutes, two explosions occurred in quick succession (0.5 - 2 seconds apart). The operator and one passenger stated that the force of the second explosion propelled the operator from the helm seat back over the transom into the water. The flash fire set the clothing of the other occupants afire. Four of the occupants either jumped or were thrown overboard, and the remaining two occupants were taken aboard a nearby boat manned by Coast Guard Auxiliary personnel. Three of the occupants were still hospitalized at the time of the investigation. The boat was towed back to the marina by a Coast Guard Auxiliary boat.

1.0 BOAT OCCUPANT DATA

Occupants	Sex	Age	Weight	Swimming Ability	Boating Experience	Formal Boating Instructions	PFD Worn
Operator	M	27	160	Excellent	>400 hr	C.G. Aux.	No
Passenger	M	54	160	Good	>500 hr	C.G.Aux.	No
Passenger	F	54	120	Good	>500 hr *	None	No
Passenger	F	76	160	Non-swimmer	Very little	None	No
Passenger	M	17	155	Good	Very little	None	No
Passenger	F	17	110	Poor	Very little	None	No

* Very little as operator, usually as passenger.

1.1 Owner/Operator

He was a member of the local Coast Guard Auxiliary and had completed [illegible]liary boating safety course. He seemed to be very knowledgeable concerning the safe operating procedures for boats under 30 ft (cabin cruiser class). He was aware of the possibility of explosion caused by fuel vapors in the type boat he owned and operated. It was apparent from the interview that he was very thorough in his pre-startup and underway safety procedures concerning the operation of his boat. He seemed to be of average intelligence and physical condition and was employed as a clerk in his father's retail candy store.

1.2 Passengers

Two of the passengers, the 17 year old male and the 76 year old female, were still in the hospital at the time of the investigation. The 17 year old female had been released from the hospital the day before the investigation. The 54 year old passenger (father of the owner/operator) was the only passenger available for interview. He was the owner/operator of a seemingly prosperous retail candy store and seemed to be of average intelligence and physical condition. He was a member of the local Coast Guard Auxiliary and had completed the auxiliary boating safety course. It was apparent that he was an experienced boat operator, but he did not seem to be as safety conscious concerning operating procedures as the owner/operator. According to the Coast Guard personnel interviewed who knew the other passengers aboard, they were of normal intelligence and physical condition.

2.0 ENVIRONMENT

The sky was clear and the visibility was excellent. The recorded air temperature was 71°F and the water temperature was approximately 50°F. The wind was from the northeast at four knots and the water was calm. The water depth at the accident site was 15-20 ft.

3.0 NARRATIVE DESCRIPTION OF ACCIDENT

3.1 Pre-Accident

On the day of the accident, the owner/operator (1) and his father (Passenger No. 2) worked at the candy store until 1700. The activities of the other passengers during the day is unknown. After closing the store, (1) and (2) went to a local restaurant for dinner. They each had two beers before dinner and a martini after dinner. After dinner the men went home, and (1) and his brother (Passenger No. 5) went to the marina where (1)'s boat was stored. At approximately 1900, (1) and (5) started preparing the boat for the annual blessing of the boats ceremony scheduled to begin at 2100. The deck plates over the fuel tank and engine were removed to vent the engine compartment. No fuel vapor could be detected when the plates were removed. A small amount of water in the bilge was evacuated by the bilge pump. The operator put 10 gallons of fuel in the fuel tank, bringing the level to approximately 1/2 full. The deck plates were put in place and (1) and (5) left the boat at approximately 1945.

All the occupants attended the on-shore ceremonies from 2100 until approximately 2115. (1) and (5) returned to the boat, and (1) turned on the engine compartment blower. Within 10 minutes after the blower was started, the other occupants boarded the boat. (1) then started the engine and began maneuvering his boat at idle speed (450 rpm) to join the procession as the thirteenth boat in a line of 20 boats. After approximately 10 minutes, the involved boat passed between the breakwater and the harbor master's station where his boat was blessed. After exiting the harbor, (1) increased the engine rpm to 500, and immediately thereafter the engine seemed to lose power and died. (1) thought that the engine stoppage had been caused by the engine idling for a long period of time. He re-started the engine and got underway at 500 rpm. The lines of boats were spaced approximately 200 ft apart.

3.2 Accident

Gear and people aboard was as shown in Figure 1, and the weather as in Section 2.0. Approximately 3-5 minutes after the restart and getting underway, a low level explosion occurred in the engine compartment. Immediately thereafter (0.5-2 seconds), a medium to high level explosion occurred. From interviews with the occupants and witnesses and from the boat inspection, it is assumed that the second explosion occurred in the forward section (cabin) of the boat. Action of the occupants during and immediately after the second explosion was as follows:

Operator (1) He saw the flash flames from the first explosion, but felt very little overpressure. He started to reach for the fire extinguisher, noticing that his shirt and hair were on fire. Before he could move, the second explosion propelled him out of the helm seat back over the transom into the water a few feet from the boat. He felt a tremendous overpressure, but remained conscious. He and the passengers recalled him yelling as he was being propelled over the transom, "get out of the boat, it's on fire." He was knocked unconscious upon hitting the water and did not regain consciousness until he was deep in the water. He was disoriented and feared that he might drown before he could reach the surface. Upon reaching the surface, he could see that occupants no. 3 and 4 were still aboard the boat. He shouted to (3) for her to turn off the boat ignition, which she did. He did not see any flames in the boat at this time. He swam to the boat and climbed aboard over the stern and observed there was no fire aboard.

Passenger No. 2

He did not know if there was a single explosion or two separate explosions. He only recalled being momentarily engulfed in flames and feeling a pressure wave coming from the forward section of the passenger compartment. He saw (1) fly over him and into the water. After he saw (1) hit the water, he noticed that his own clothing was on fire, and he immediately jumped over the transom into the water to extinguish the fire. He then climbed back into the boat over the stern, followed by (1).

Passengers No. 3 & 4

The clothing and hair of these passengers were set afire by the flash fire. They extinguished their burning clothing by hand brushing. (3) turned off the boat ignition after being directed to do so by the operator. They remained on the boat until taken aboard a rescue boat crewed by Coast Guard Auxiliary personnel.

Passengers No. 5 & 6

The clothing and hair of these passengers were set afire by the flash fire. (6) was standing on the forward engine compartment cover. The explosion moved the cover out of its deck support fixturing, causing it and (6) to fall into the engine compartment. (5) helped (6) out of the engine compartment and threw her over the port side into the water. (5) then grabbed the 2-1/2 lb dry chemical fire extinguisher located at the helm and put out the fire in the engine compartment (small fire) and sprayed objects on deck such as lawn chairs, articles of clothing, etc. that had been ignited by the flash fire. It is uncertain how he extinguished his burning clothing. After he had extinguished the fire, he heard (6) shouting for help. He realized that she could not swim and was drowning. He jumped over the port side and swam to her aid. He held her head above water for approximately one minute until the crew of a Coast Guard Auxiliary boat threw him a life ring. (5) and (6) were taken aboard the rescue boat and transported to shore.

3.3 Post Accident

While (1) and (2) were climbing back into the boat, a second boat crewed by Coast Guard Auxiliary personnel pulled alongside the invoved boat and one member boarded. He helped (3) and (4) into the rescue boat and then disconnected the battery terminals to prevent a possible electrical fire. (2) grabbed a 2-1/2 lb dry chemical fire extinguisher and discharged it into the engine compartment. He did not see any flames, but felt there was a possibility of a re-flash. The boat was drifting out from shore, so (1) went forward and deployed the anchor. After it was determined that the fire would not restart, the involved boat was towed back to

the marina by a third C.G. Auxiliary boat and put in an isolated slip. All of the occupants were taken to a local hospital. Injuries sustained as a result of the fire and explosion were as follows:

Operator (1) Minor burns on hands, arms, face, and hair. Treated at local hospital and released.

Passenger (2) Minor burns on hands, arms, face, and hair. Treated at local hospital and released.

Passenger (3) Minor burns on legs, arms, face, and hair. Treated at local hospital and released.

Passenger (4) First and second degree burns on legs and face. Treated at local hospital and released.

Passenger (5) Second and third degree burns on 52 percent of his body. Treated at local hospital and transferred to regional burn center.

Passenger (6) Second and third degree burns on back, arms, and hands. Treated at local hospital and transferred to regional burn center.

Refer to Photograph 1 and Figure 2 for accident area.

Time Sequence

1700	(1) and (2) closed business.
1710-1800	(1) and (2) had dinner and went home.
1800-1900	(1) and (5) went to marina to ready boat.
1900-1945	(1) and (5) fueled and readied boat for cruise.
1945-2115	All occupants attended on shore ceremonies.
2115	(1) and (5) returned to boat, and (1) turned on engine compartment blower.
2125	Other occupants boarded the boat and engine was started.
2135	Involved boat passed harbor master station where boat was blessed.
2136	Increased rpm to 500, engine stopped and restarted.
2140	Two explosions occurred in quick succession (0.5 - 2 seconds apart). Operator blown over transom, clothing of other occupants set on fire.
2140-2141	(2) jumped overboard, (6) thrown overboard, (5) extinguished small fire in engine compartment and jumped overboard to aid (6). (3) turned off ignition, stopping engine.
2141-2145	(1) and (2) climbed back into the boat. C. G. Auxiliary member helped (3) and (4) into rescue boat. (2) discharged fire extinguisher into engine compartment. (1) deployed anchor. C. G. Auxiliary member disconnected battery. (5) and (6) taken aboard a C. G. Auxiliary vessel.
2200	Involved boat towed to isolated slip in marina.

4.0 FACTS FROM THE BOAT INSPECTION

The boat was a wooden 1964 model Owens inboard cabin cruiser, powered by a 185 horsepower Chevrolet engine. The overall length was 28 ft with a maximum beam of 124 in. The boat structure and components appeared to be in very good condition for a 1964 model.

The interior of the boat showed very little fire damage resulting from the explosion. The only obvious visible evidence that a flash fire had occurred was the burned and melted nylon webbing of the lawn chairs located in the aft section of the passenger compartment. It was evident from the warped engine hatch covers and heavy articles strewn about in the head and cabin area that the explosion caused a significant overpressure in the engine compartment and forward section of the boat. Refer to Photographs 2-6.

5.0 PSYCHOLOGICAL AND HUMAN FACTORS

The operator seemed to be very knowledgeable concerning the safe operation of his boat. As far as could be determined, he always exercised good safety procedures in the pre-start and underway operation of his boat. As an active Coast Guard Auxiliary member, he had been involved in several fire/explosion rescue operations and was aware of the fire hazards related to fuel vapor buildup in inboard boats.

Prior to the accident, the safety procedures used by the operator seemed to be adequate. He removed the deck plates covering the engine compartment and fuel tank and allowed the compartment to air out sufficiently before starting the engine. He pumped the bilge dry and visually verified that no water remained in the bilge. He started the engine compartment blower approximately 10 minutes prior to starting the engine and kept it on until the explosion occurred.

The operator admittedly had been drinking prior to the accident; however, alcohol is not considered a factor in this accident. The behavior of the occupants of the involved boat after the accident was such that the rescue personnel interviewed were not aware that alcohol had been consumed by anyone aboard.

6.0 PROBABLE CAUSE OF ACCIDENT

The explosion was caused by a fuel leak in the engine compartment, resulting in a buildup of fuel vapor level to the explosive range.

At the time of the investigation, the boat was essentially in the same condition as it was immediately after the explosion. No repairs had been made and the engine had not been started. A close visual examination of the engine compartment revealed a frayed flexible line between the fuel pump and fuel filter. To ascertain if this was the location of the fuel leak, the ignition system was disconnected and the engine turned over by the starter. Fuel immediately began to spray from the suspected hose. The location of the leak was at a metal hose clamp on the fuel filter input (see Photographs 7-10). Since the engine had been running for a long period of time prior to the explosion, it is assumed that the hose ruptured after the engine had been started. The leakage rate from the ruptured hose was estimated to be approximately one-fifth quart per minute. Taking into consideration that some of the fuel vapors escaped to the atmosphere, the amount of raw fuel required to cause an explosion of this intensity without a resulting fire could have been as much as one quart. Therefore, it is believed that the fuel leak occurred approximately five minutes prior to the explosion. The ignition system on this engine was not explosion proof; therefore, the igniting source was probably one of the ignition system components.

A fuel vapor detector installed in the engine compartment would have probably prevented this accident.

7.0 DYNAMICS/ANALYSIS OF THE ACCIDENT

The pressure from the fuel pump and the circumferential rupture in the fuel line would have caused the fuel to escape as a spray rather than a stream. The heat of the engine was sufficient to vaporize this spray rapidly leaving a very small amount of raw fuel. The engine compartment was well sealed except for a two inch hole on each side of the forward bulkhead. These holes were for routing of engine control and monitor lines. A portion of the fuel vapor in the engine compartment escaped through these holes to the cabin and concentrated near the floor in the walkway. The first explosion occurred in the engine compartment with a force

only sufficient to displace the engine compartment hatch covers. The flash flames from the engine compartment were most likely intense enough to burn some of the occupants.

The second explosion which was more violent occurred in the cabin. The explosion was caused by flames propogating through the routing holes igniting the fuel vapor in the walkway. The force was sufficient to blow open the cabin hatch and eject the operator from the helm seat and aft over the transom. The flash flames resulting from this explosion were most likely great enough to cover the entire area where the occupants were located and probably caused most of the burn injuries to the occupants. Since there was very little fire after the explosion, it can be assumed that most of the fuel was in vapor form at the time of the explosion.

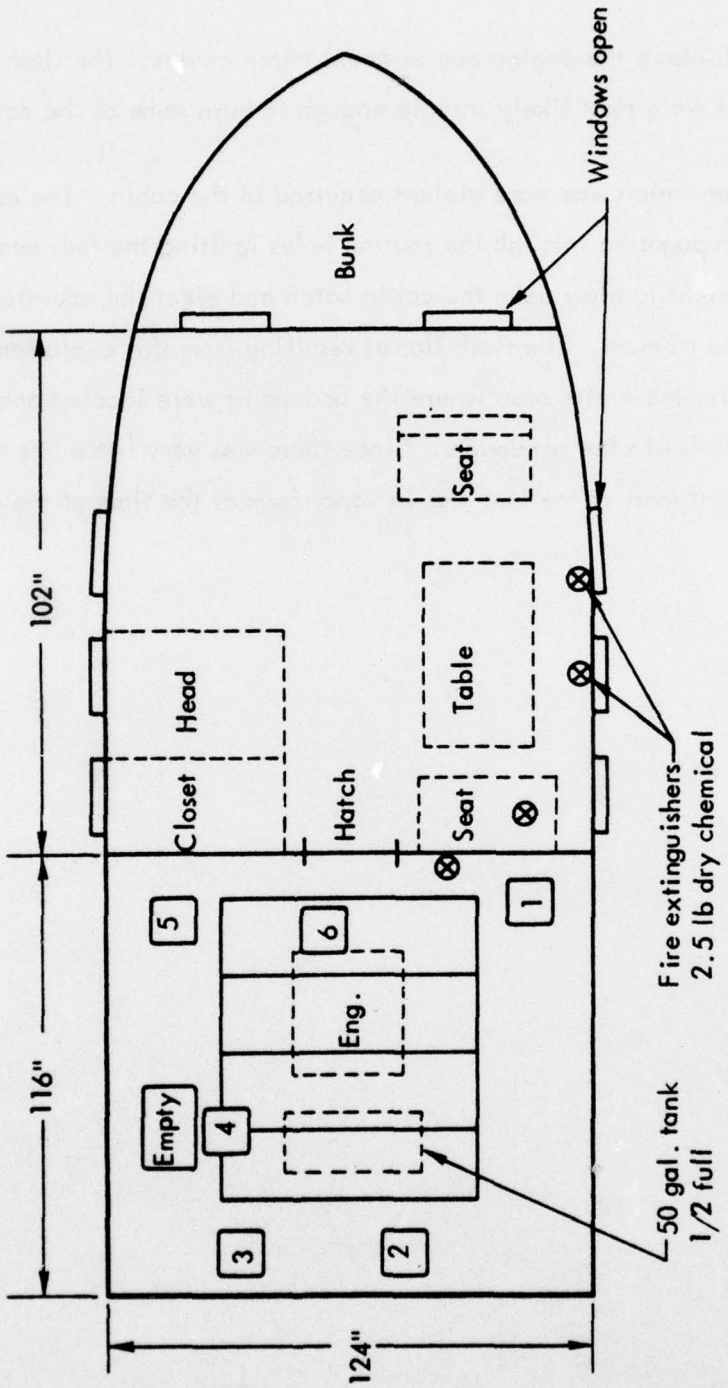


Figure 1. Boat Load Distribution At Time Of Accident

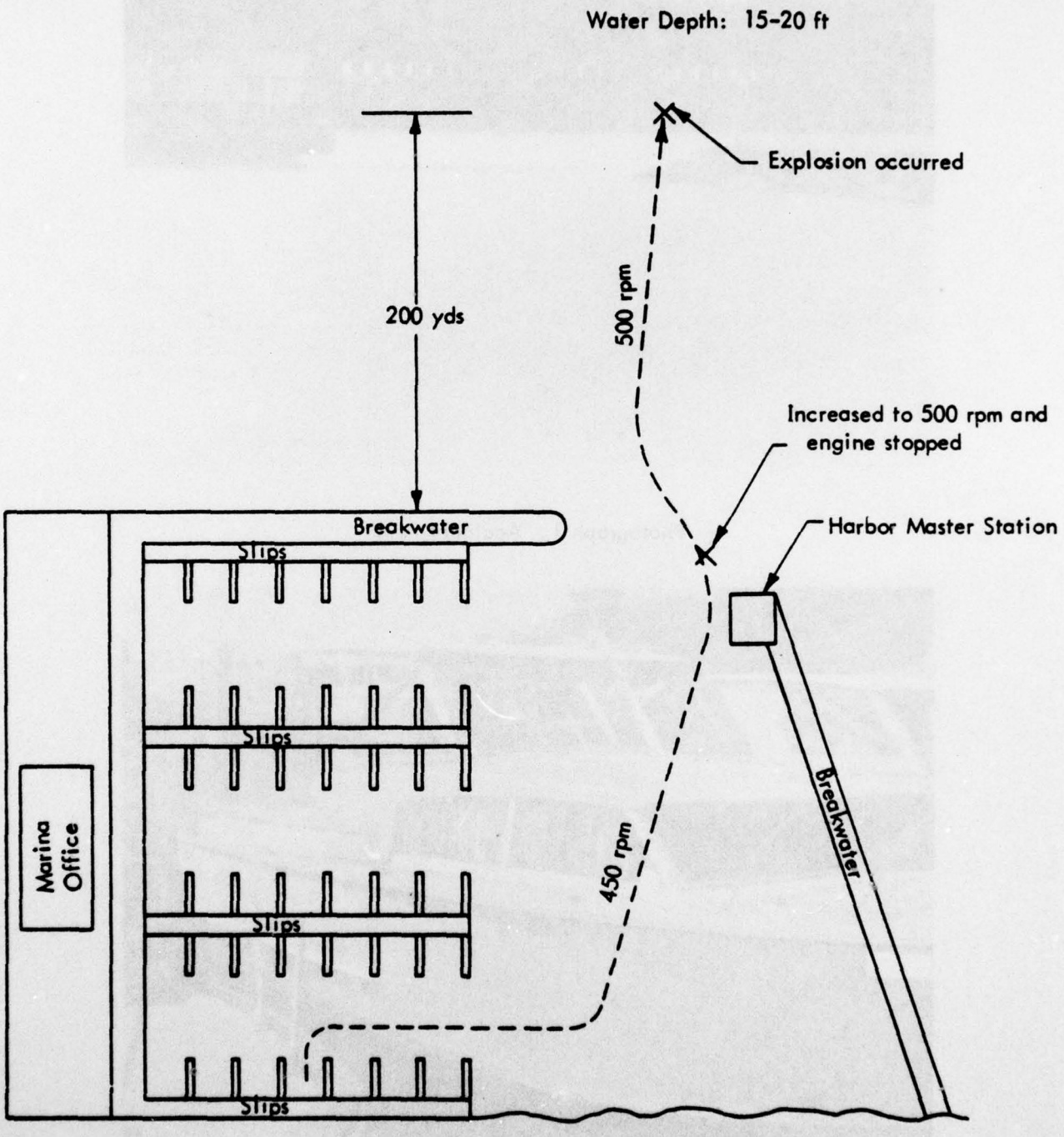
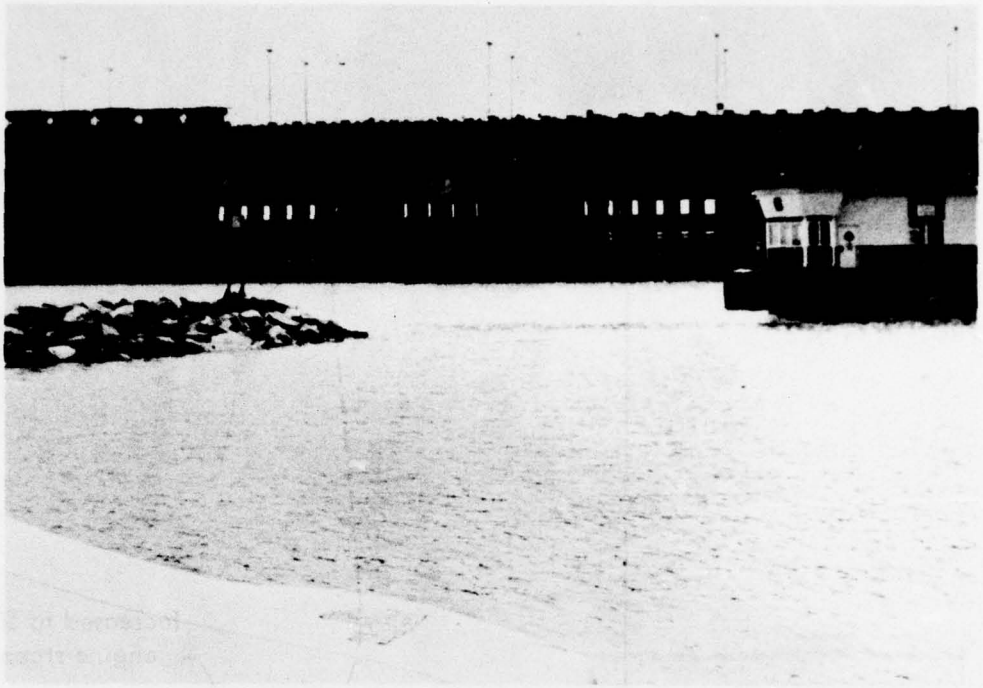
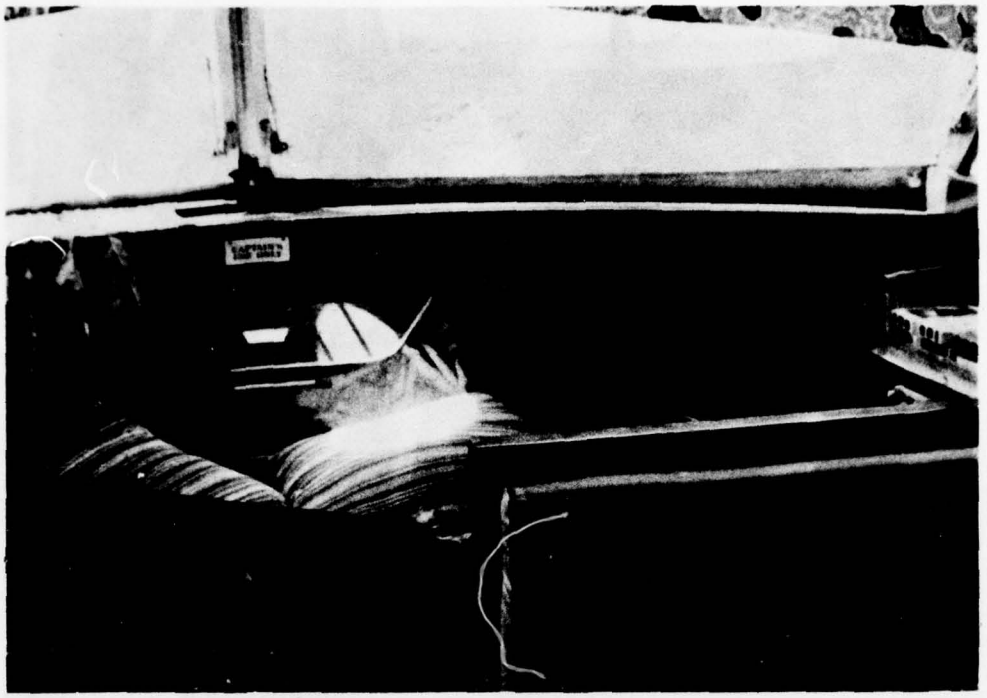


Figure 2. Accident Area

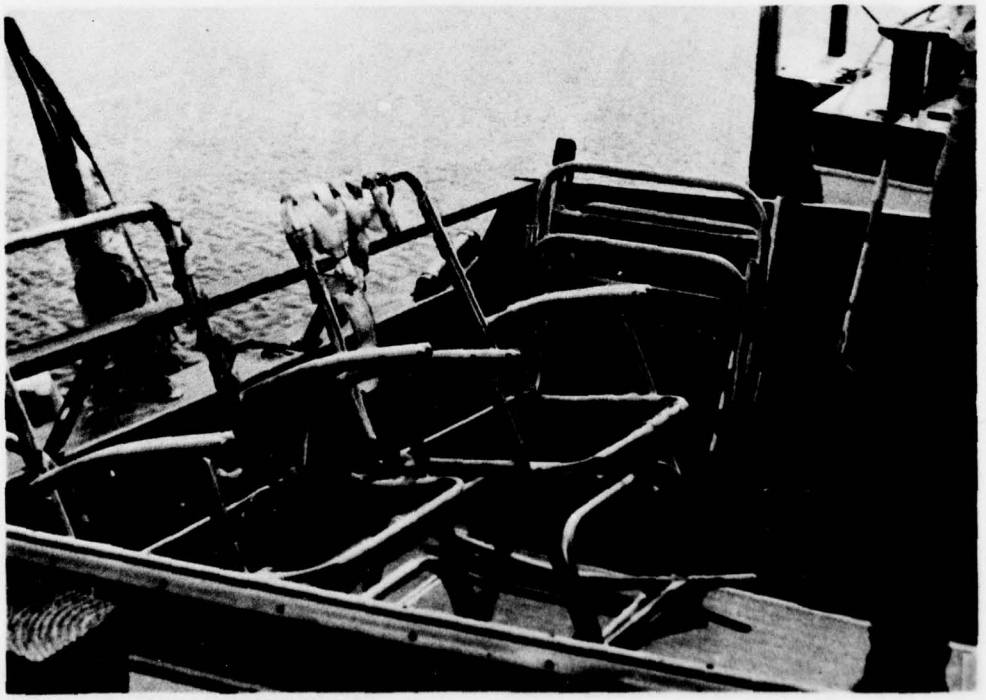


Photograph 1. Accident Area

Photograph 2.



Photograph 3.



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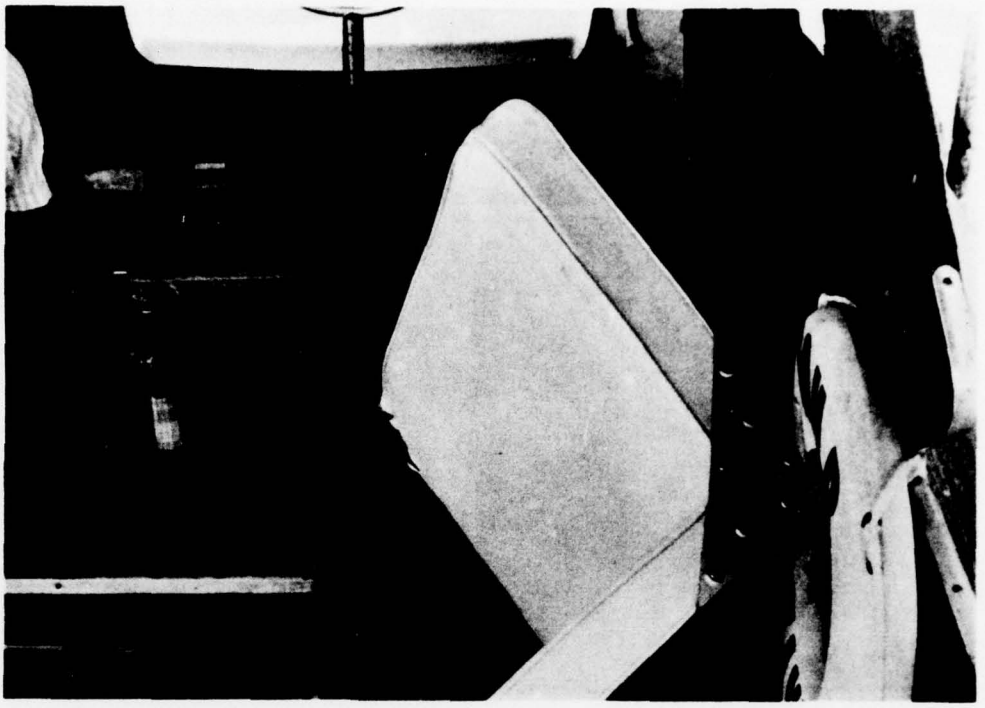
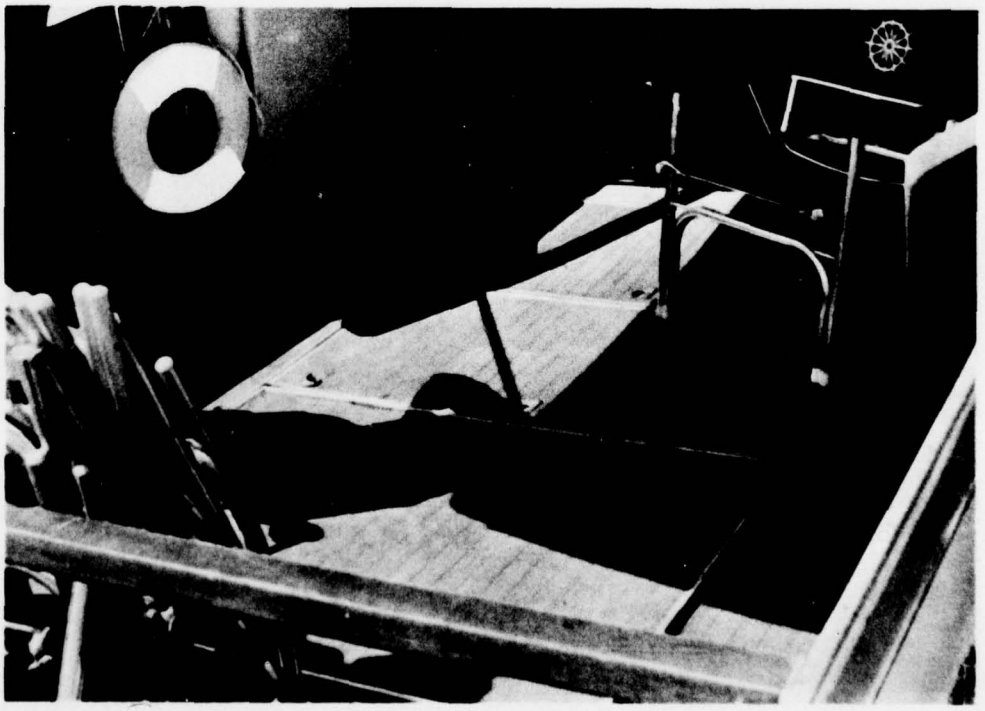
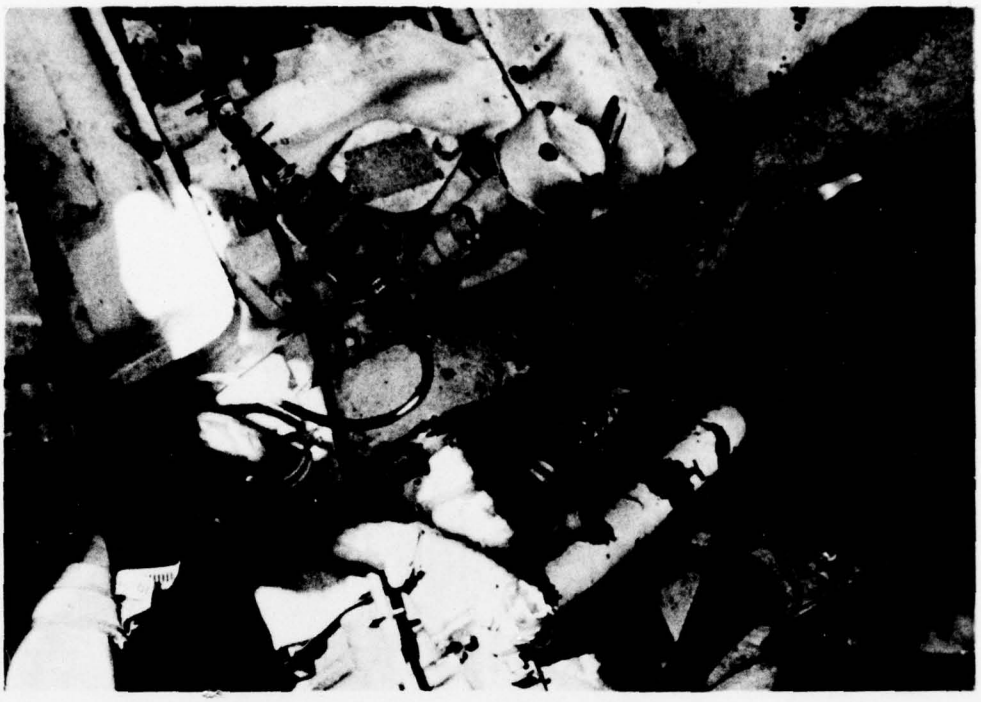


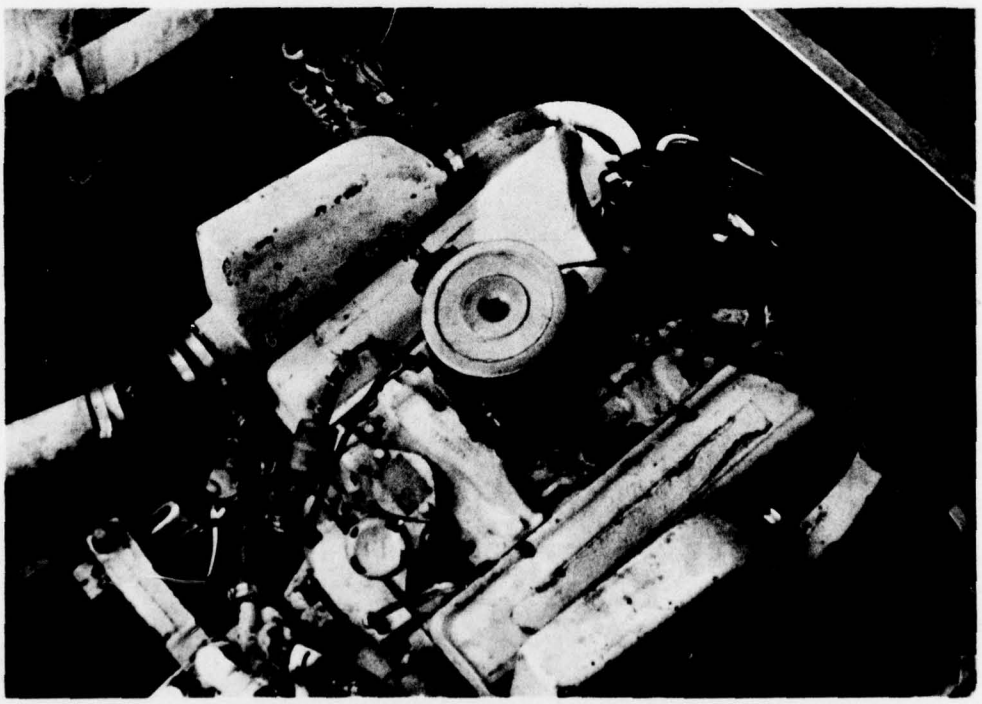
Photograph 5.



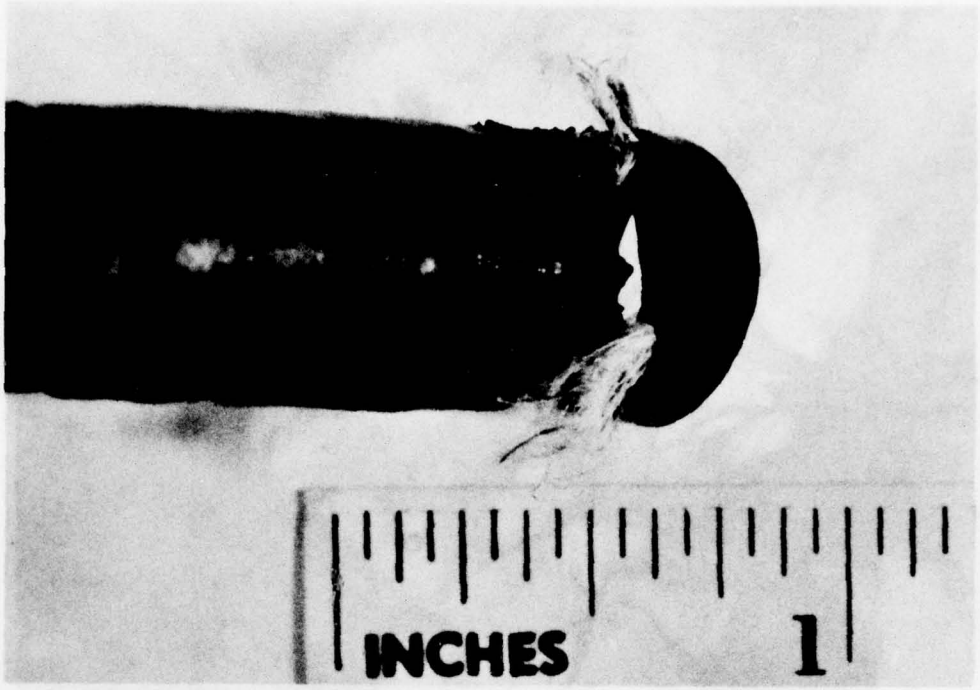
Photograph 6 .



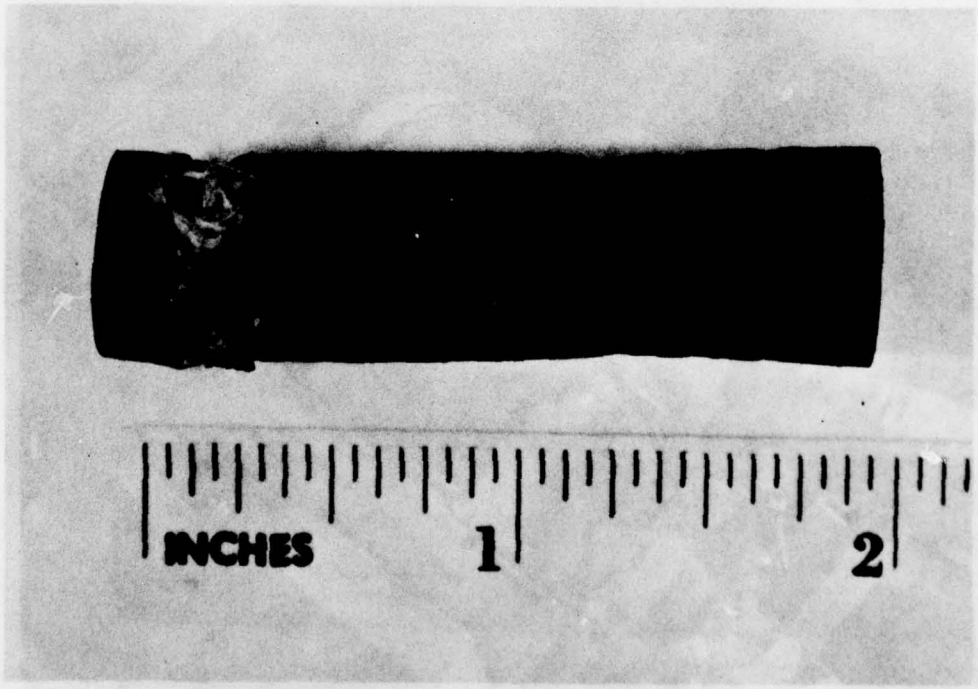
Photograph 7.



Photograph 8.



Photograph 9. Ruptured Fuel Line



Photograph 10. Ruptured Fuel Line

APPENDIX F

ACCIDENT INVESTIGATION REPORT

Date of Investigation: October 16, 1975

Date of Accident: Mid-October, 1975

Investigation: Fire/Explosion No. 75-06

SUMMARY — WYLE ACCIDENT NO. 75-712

The accident reported herein involved a 23 ft inboard/outdrive boat powered by a 190 horsepower OMC engine. The type of accident was an explosion with a subsequent fire, which destroyed the boat beyond reasonable repair. No injuries were sustained by the sole occupant aboard.

At approximately 1500 in mid-October, 1975, the owner/operator of the involved boat set out on a fishing trip from a marina located in southeastern Virginia. He traveled up an island waterway to a calm bay arriving at approximately 1510. He fished in the bay for approximately one hour. During this time he had heard on his on board CB radio that the fishing was good in the inlet located approximately 20 minutes away. He traveled back down the island waterway to the inlet, arriving at approximately 1630. He started trolling at idle speed back and forth from the mouth of the inlet to approximately 1/2 mile out from the mouth of the inlet. He heard a low level explosion in the engine compartment and went aft to see what had happened. He moved the engine cover forward to look in the engine compartment. He saw flames in the lower forward section of the engine well. He was afraid that the fuel tank located immediately forward of the fire would explode, so he grabbed a PFD and jumped overboard. He swam away

from the boat thinking that an explosion would occur at any time. A small pleasure boat came to the aid of the operator approximately three minutes after he jumped in the water. The operator boarded the rescue boat and at this time noticed that the entire boat was ablaze. The rescue boat circled the burning boat at a safe distance for approximately six minutes, at which time a second boat arrived at the scene and called the Coast Guard on marine radio. The operator was then returned to the marina by the rescue boat. The fire was extinguished by a passing Navy vessel, and the boat was towed back to the marina by a local Coast Guard rescue boat.

1.0 BOAT OCCUPANT DATA

Occupants	Sex	Age	Weight	Swimming Ability	Boating Experience	Formal Boating Instruction	PFD Worn
Operator	M	31	180	Fair	>500 hrs	None	No

It was apparent from the interview that the owner was an experienced boat operator. He had owned and operated two outboard boats under 20 ft in length and two inboard/outdrive boats over 20 ft in length. He was a heavy equipment operator by trade and seemed to be of average intelligence and physical condition. He had fractured his right wrist approximately one month prior to the accident, and at the time of the accident he had a 3/4 length cast on his right arm.

2.0 ENVIRONMENT

The sky was clear and the visibility was good. The recorded air temperature was 81°F and the water temperature was comfortably warm. The wind and water was calm.

3.0 NARRATIVE DESCRIPTION OF ACCIDENT

3.1 Pre-Accident

Approximately one month prior to the accident, the operator had fractured his right wrist in a motorcycle accident which required putting a 3/4 length cast on his right arm. The cast was on at the time of the accident. The cast prevented him from performing his duties as a heavy equipment operator; therefore, he had been on sick leave prior to the accident. On the day before the accident, the operator had decided to go on a fishing trip in the area where the accident occurred. He topped off the fuel tank and proceeded toward the fishing area. When he arrived at the inlet, he could see that the water was rough (3-4 ft swells) and decided to return to the bay to fish. After spending approximately two hours fishing in the bay, he returned to the marina and secured his boat. He had noticed that the motor was running unusually rough at idle speed during the fishing trip. He stated that on the night

before the accident, he had stayed home and received a normal night's sleep. On the day of the accident, he was at his doctor's office at 1415 to have his arm x-rayed. At approximately 1430, he left the doctor's office for the marina where he planned to take his boat on a fishing trip. Arriving at the marina, he stowed the fishing gear that had been left aboard after the fishing trip on the previous day. He turned on the engine compartment blower approximately two minutes prior to starting the engine. After the engine started, he turned off the blower. He did not visually inspect the engine or take on any fuel prior to starting the engine. He left the marina at approximately 1500 and traveled up the inland waterway at slow speed to the south end of the bay. He troll fished at idle speed for approximately one hour. During this time he had heard on the CB radio aboard his boat that the water was calm in the inlet and fishing was good. He had not caught any fish in the bay and decided to go to the inlet. He traveled down the inland waterway arriving at the mouth of the inlet at approximately 1630. He started troll fishing at idle speed back and forth from the mouth of the inlet to approximately 1/2 mile out in the open water. The engine stopped two or three times during the trolling operation, but was easily restarted. The operator stated that he felt the engine had stopped due to the low operating rpm and because the engine was running rougher than normal.

3.2 Accident

After fishing for approximately 40 minutes, the boat was heading seaward and approximately 1/2 mile off shore. Gear aboard was as shown in Figure 1, and the weather as in Section 2.0. The operator heard a noise which sounded like a muffled explosion in the engine compartment. After the noise, the engine continued to run. The operator turned off the ignition and went aft to investigate the noise he had heard in the engine compartment. He slid the engine cover forward sufficiently to look at the engine. He saw a small fire in the lower forward section of the engine well which seemed to increase in size as soon as the engine cover was slid forward. The operator grabbed and AK-1 PFD which was stowed on the starboard side of the boat and jumped over the starboard side into the water.

3.3 Post Accident

He felt the boat was going to explode at any time because the fuel tank was located immediately forward of the area of the fire. He held the PFD between the cast on his right arm and his chest and used his left arm and legs to swim away from the boat. After approximately one minute from the time he had jumped overboard, he was what he considered a safe distance from the boat. He turned around and observed that the fire was concentrated in the aft section of the boat, and the smoke being emmitted from the fire was white in color. Within the next two minutes, the fire had spread over the entire boat, and the smoke color had changed to black. At this point, a small boat that had noticed the boat fire pulled alongside the operator and took him aboard. The rescue boat circled the burning boat for a few minutes until a second small boat that had seen the fire arrived on the scene. The second boat was equipped with a marine radio and called the nearest Coast Guard station and reported the fire. During the investigation, personnel at the Coast Guard station informed the investigator that the initial report was received by land line; therefore, apparently, somesone ashore called the fire in before the radio call was made by the second boat. The operator was taken back to the marina where he gave the details of the accident to local marine police investigators. The operator received no injuries as a result of the fire. Within 30 minutes after the explosion, the boat fire was extinguished by a passing Navy vessel. After the fire was extinguished, the boat was towed back to the marina by a Coast Guard rescue vessel.

Refer to Figure 2 for sketch of the accident area.

3.4 Time Sequence

1430	Left Doctor's office.
1445	Arrived at marina.
1458	Turned on engine compartment blower.
1500	Started engine and turned off blower.
1510	Arrived at south end of bay and started troll fishing at idle speed.
1610	Left bay for inlet.
1630	Arrived at mouth of inlet and started troll fishing at idle speed.
1710	Operator heard low level explosion in engine compartment. He turned off ignition, slid the engine cover forward, saw flames, grabbed a PFD, and jumped overboard. Approximately 30 seconds lapsed from the time he heard the explosion until he jumped overboard.
1712	After swimming a safe distance from boat, he turned and observed fire was in aft section and white smoke was being emitted.
1714	Fire spread over entire boat and smoke was black. Operator picked up by rescue boat.
1714-1720	Rescue boat circled involved boat.
1720	Second boat arrived and called C. G. on radio.
1750	Fire extinguished by Navy vessel.
1810	Boat towed to marina by C. G. rescue vessel.

4.0 FACTS FROM THE BOAT INSPECTION

The boat was a fiberglass 1974 model Fiberform I/O powered by a 190 horsepower OMC engine.

The interior of the boat was completely gutted by fire as shown in Photographs 1-7. The fuel tank was installed below deck on the longitudinal centerline approximately one foot forward of the engine compartment. The fuel filler hose ran from the top aft end of the tank down alongside the engine on the port side, then up at approximately a 45 degree angle to the filler cap located on top of the transom, port side. The vent line was routed with the filler hose from the tank around the engine to the vent fitting located on top of the transom, port side (see Figure 3). A flexible feed line ran from the tank top down to the fuel pump located at the bottom front port side of the engine. A rigid steel tube ran from the fuel pump output to the carburetor. Only charred pieces of the flexible lines in the engine compartment were found. According to the owner, no modifications had been performed on the boat, and with the exception of a new battery installed by the owner three months prior to the accident, no components had been repaired or changed. See Photographs 8-11 for undamaged boat similar in interior configuration.

5.0 PSYCHOLOGICAL AND HUMAN FACTORS

The operator seemed to be very lax concerning the operation of his boat. The engine was running rough on the day before the accident, but he made no attempt to determine the cause of the rough running condition. On the day of the accident, prior to getting underway, he did not inspect the engine compartment or bilge. He stated that his boat did not leak and he did not consider the rough running condition bad enough to be of concern. His boat was relatively new and he did not feel it was necessary to perform a visual inspection of the engine compartment or bilge prior to each outing. He stated that the engine compartment was equipped with a blower which should evacuate any fuel vapors prior to starting the engine.

When the operator first discovered the fire, it could probably have been easily extinguished by the fire extinguisher aboard. He decided not to stay aboard and try to extinguish the fire for two reasons: (1) he saw that the fire was near the fuel tank and was afraid the fuel tank

would explode, (2) he had read in the paper a few days before the accident that two men had been severely burned in a boat fire which occurred in a nearby body of water.

Although alcohol is not considered a factor in this accident, the operator stated that he had not consumed any alcohol on the day of the accident.

6.0 PROBABLE CAUSE OF ACCIDENT

The interior of the boat was so badly burned that it was impossible to determine the exact cause of the fire, other than it was fuel related. The steel line connecting the fuel pump to the carburetor was removed from the boat and pressure tested. No leaks were found in the line and the end fittings were in good condition. The fuel tank was removed from the boat (tank was full of water and fuel) and checked for leaks. The tank did not leak, and all fittings were tight and in good condition. The flexible fuel filler hose is considered the most likely source of the fuel leak. The hose was routed in such a manner that the lowest section of the hose was located on the port side of the engine. After fueling, this low section would always be full of fuel. During engine operation, the hose could have been frayed by vibration at the low section, causing fuel in the hose during and after the fueling operation to leak into the engine compartment. The engine had been running long enough to heat the engine compartment sufficiently to cause the fuel to vaporize to an explosive mixture level. The source of ignition could not be determined.

The explosion was of a very low intensity. Since the engine cover was not displaced by the explosion, pressure relief vents for the engine compartment would have been of no benefit in this situation. A "fire extinguisher port" could have been of value if the operator had chosen to fight the fire.

7.0 DYNAMICS/ANALYSIS OF THE ACCIDENT

The intensity of the explosion was not high enough to displace the engine cover. Immediately after the explosion, the fire was small and was confined to the forward section of the motor well. The intensity of the fire increased somewhat when the engine cover was slid forward, but could have probably been extinguished easily with a fire extinguisher. Apparently, there was enough raw fuel in the engine well to ignite flammable material in the fuel fire area. The fire then spread forward along the carpet and other flammable material in the passenger compartment until the complete interior of the boat was on fire. The boat burned to the water line before the fire was extinguished. There was sufficient flotation material in the boat to keep it afloat after the fire was extinguished.

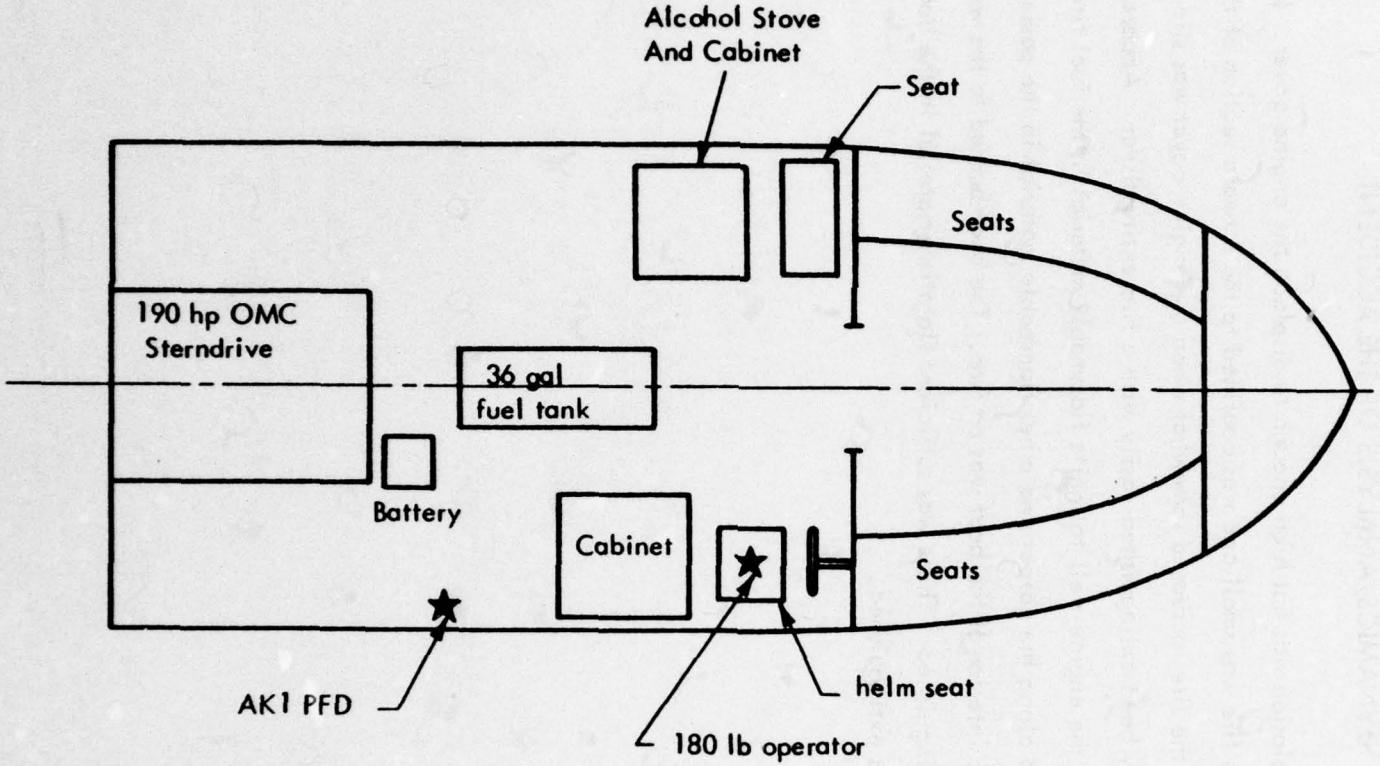


Figure 1. Location Of Operator And Equipment At Time Of Accident

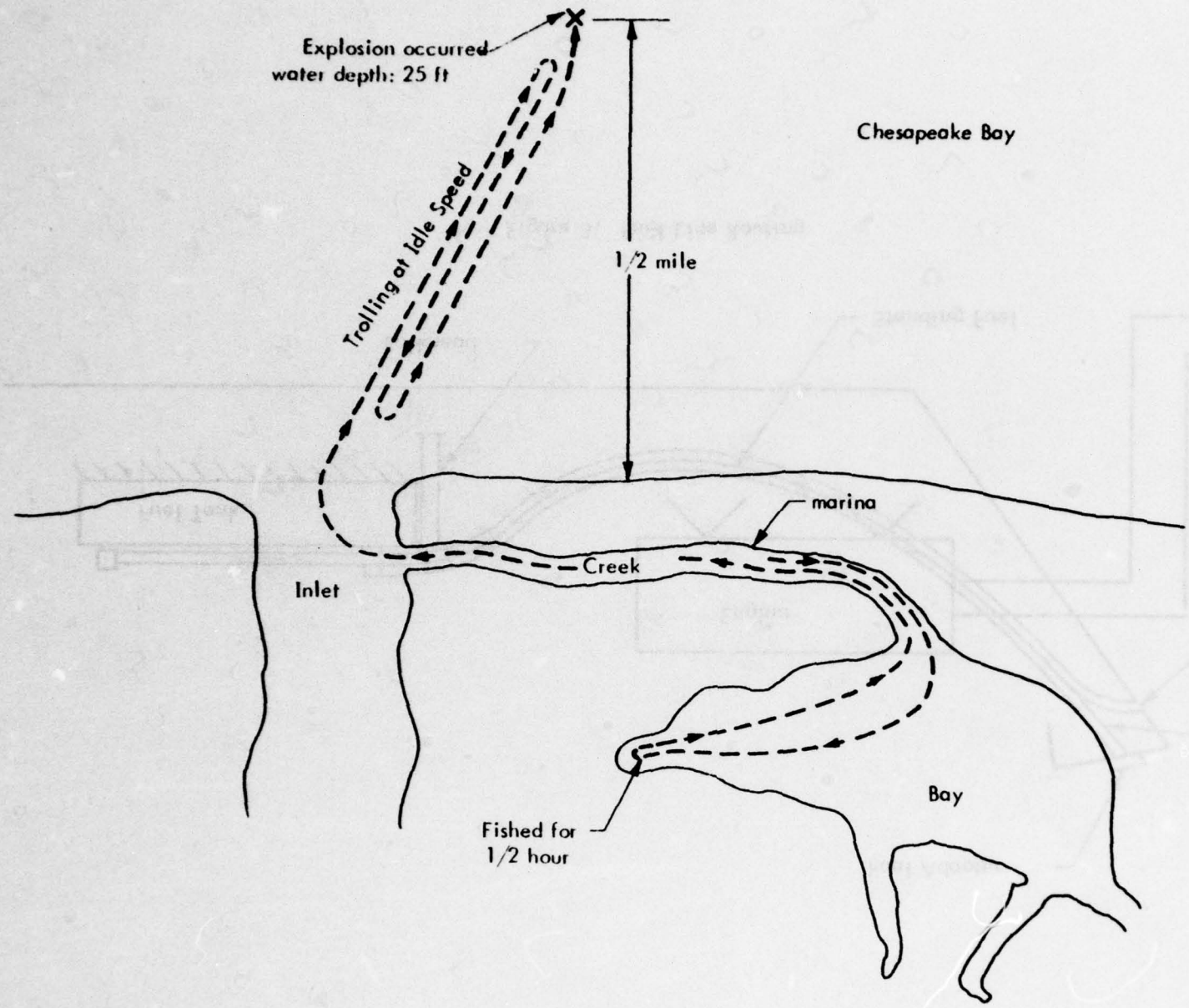


Figure 2. Accident Area

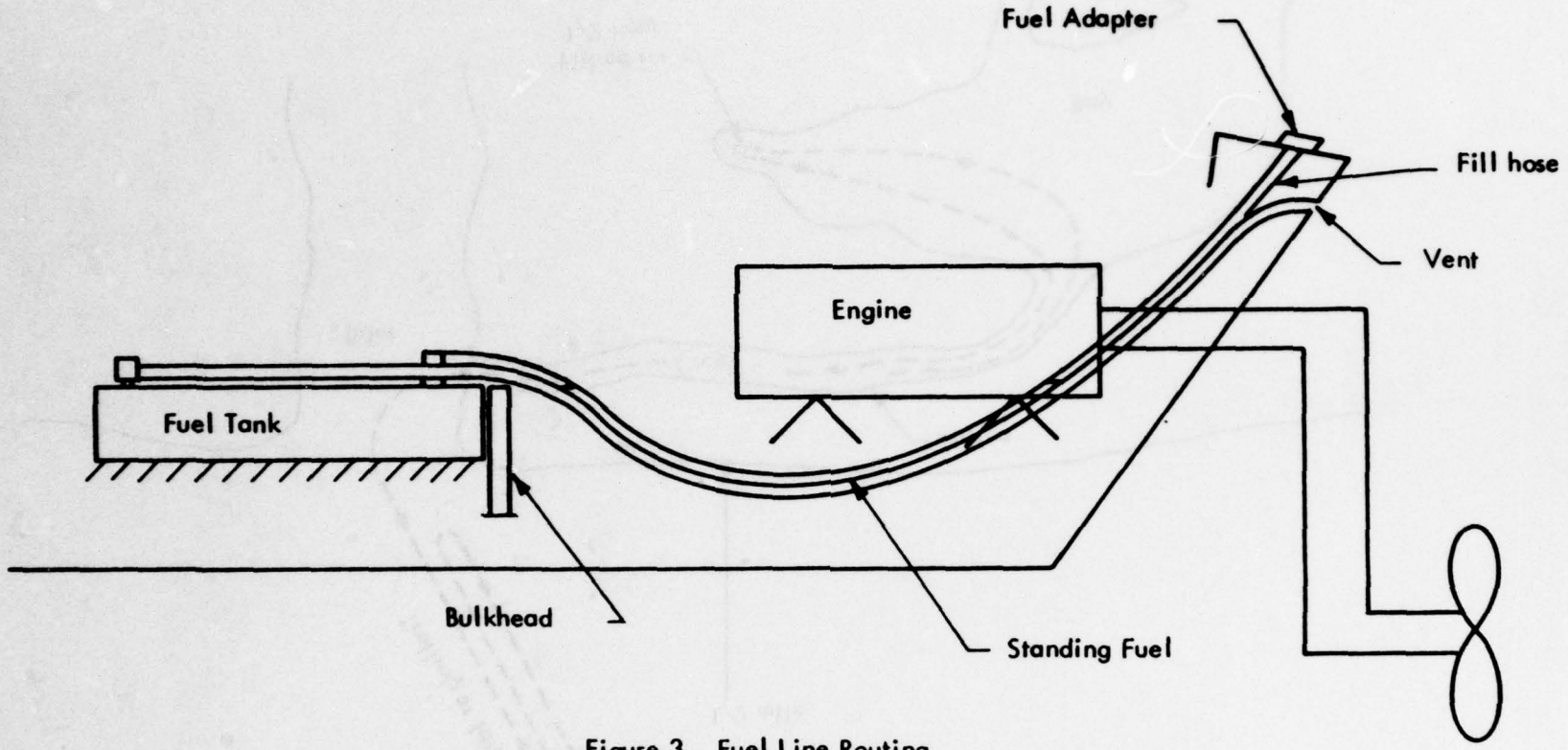
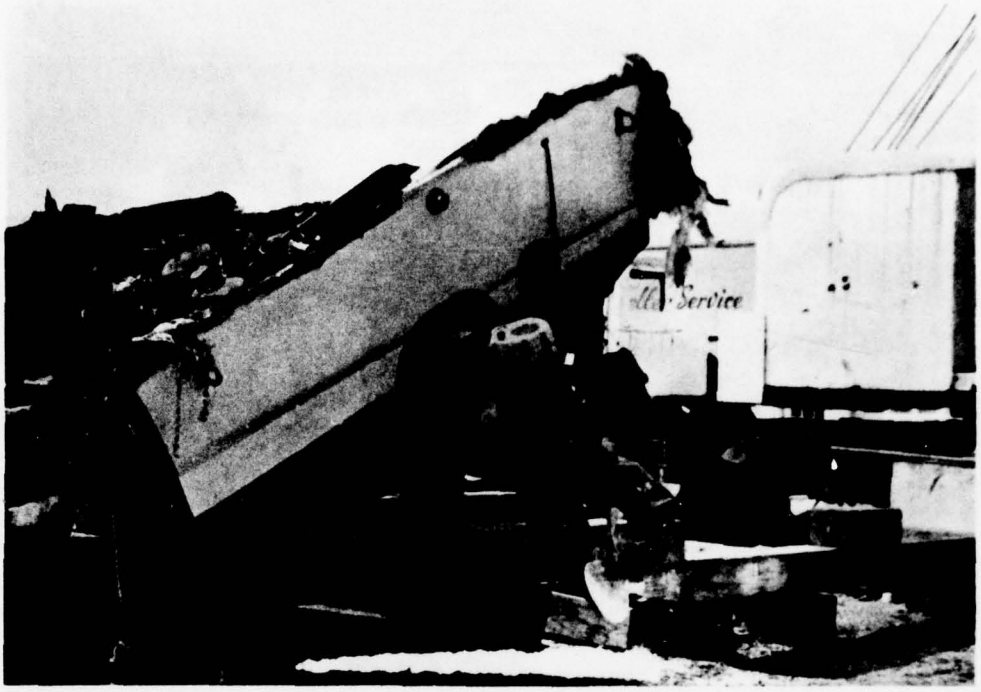


Figure 3. Fuel Line Routing

Photograph 1

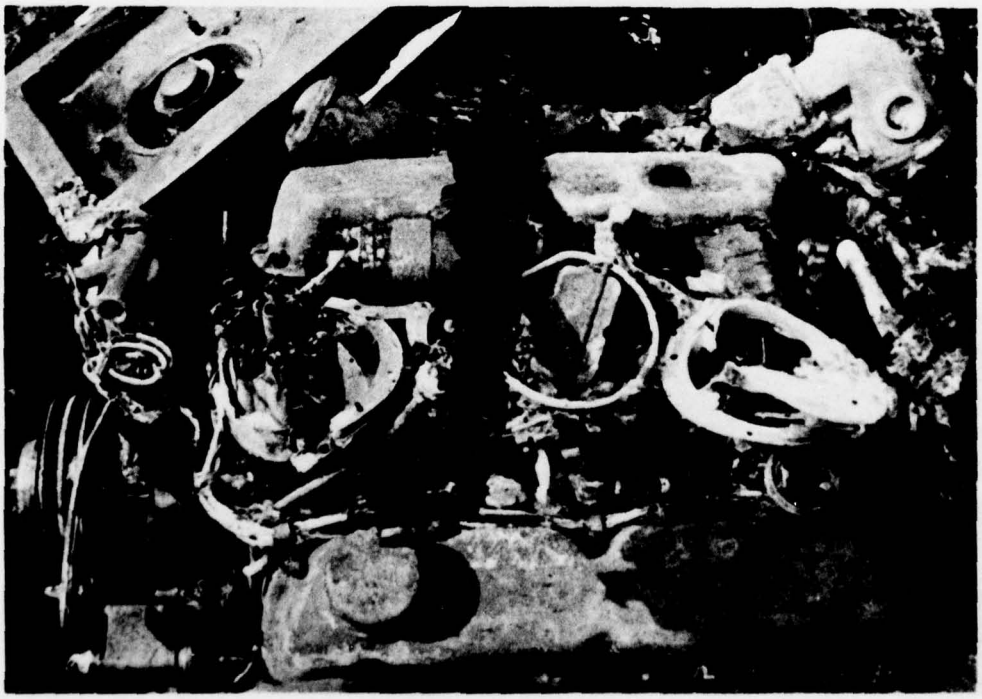
Photograph 2



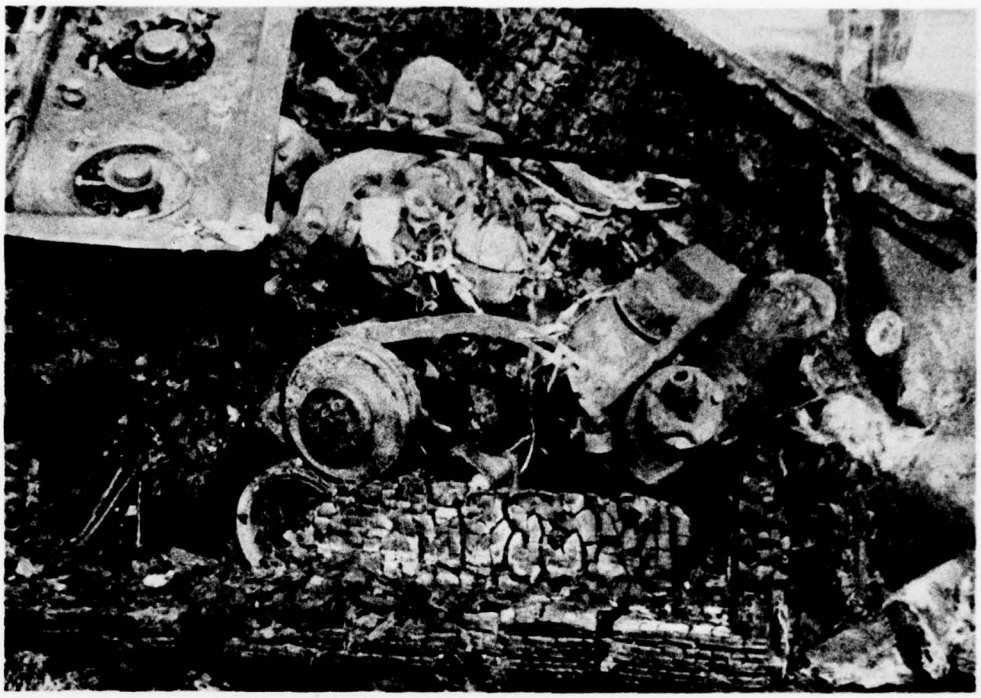
Photograph 3

Photograph 4

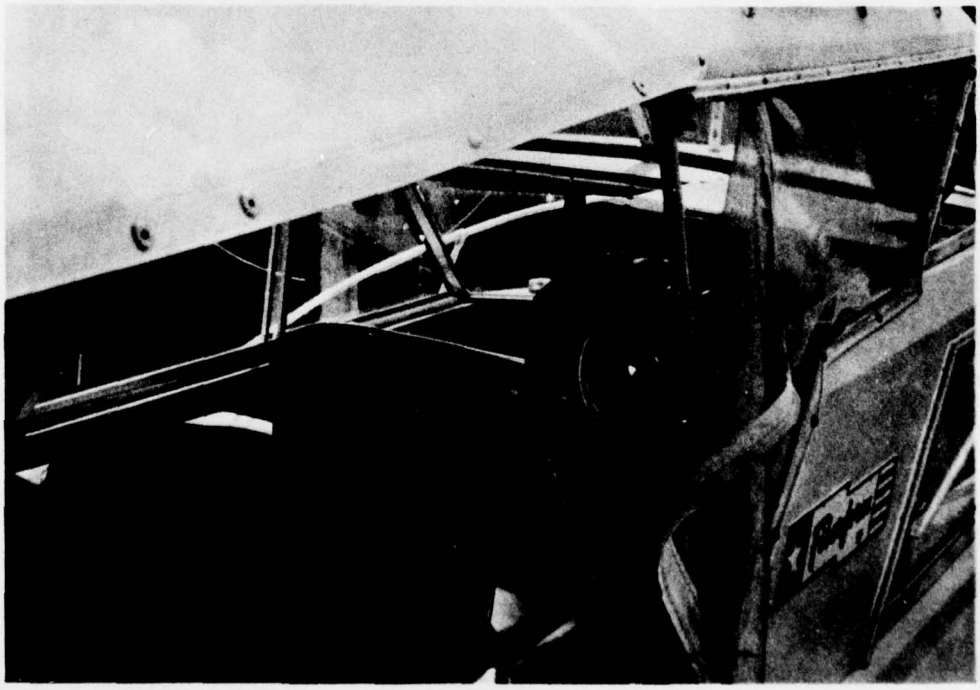
Photograph 5



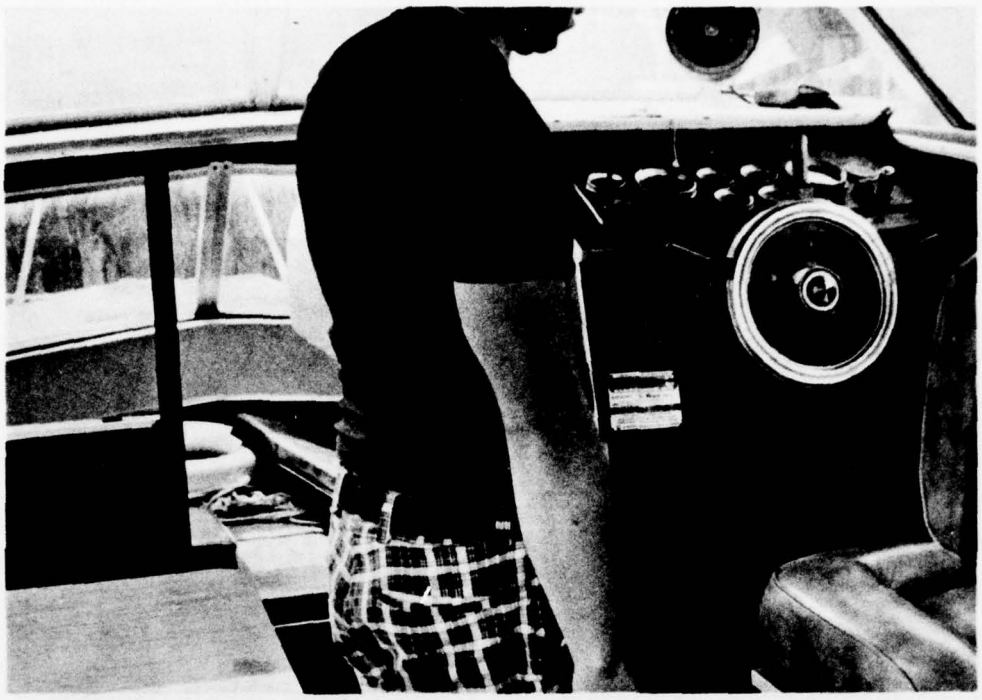
Photograph 6



Photograph 7

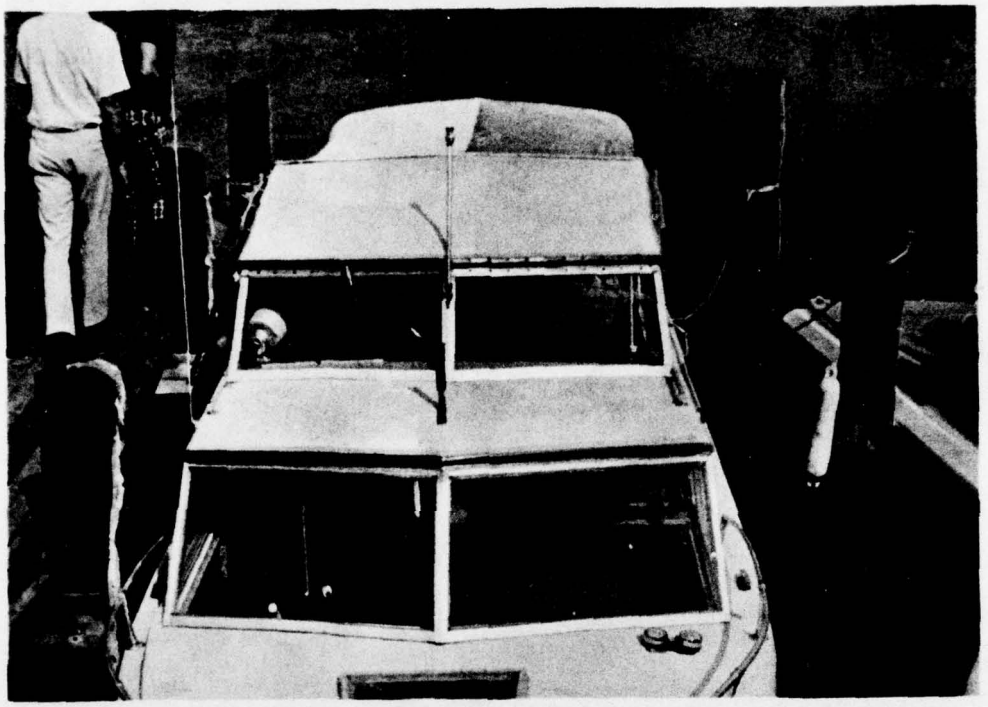


Photograph 8



Photograph 9

Photograph 10



Photograph 11

APPENDIX G

ACCIDENT INVESTIGATION REPORT

Date of Investigation: January 14, 1976

Date of Accident: Mid-December, 1976

Investigation: Fire/Explosion No. 75-07

SUMMARY — WYLE ACCIDENT NO. 76-007

The accident reported herein involved a 28 ft Seabird inboard/outdrive powered by two 215 horsepower Mercury engines. The type of accident was an explosion with a subsequent fire, which destroyed the boat beyond reasonable repair. There were no fatalities, but one of the five people on board received severe burns.

At approximately 1130 in mid-December, 1976, five men ranging in age from 31 to 76 returned to a marina located in southern Louisiana after a weekend fishing trip. The boat was secured at the fueling dock and the fuel tank topped off by one of the occupants aboard.

While the boat was being fueled, the other occupants went inside the marina office, which was also a bar. The operator stated that he had turned the forward and aft bilge blowers on before he left the boat. After the boat had been fueled, the occupants talked to the marina owner until approximately 1150. At this time, the men started boarding the boat for the purpose of moving it diagonally across a small canal to its storage slip. The operator boarded and went directly to the helm position. Two of the other occupants boarded and were standing on the engine hatch covers. One occupant had one foot on the gunwale and one foot on the

dock, preparing to board. The remaining occupant was standing on the dock, holding the boat until everyone was aboard and the engines started. According to the operator, a violent explosion occurred as he was sliding across the helm seat to the normal operating position. He stated that he had not turned an ignition key to the start position. The operator was hit in the back and neck by an unknown object which knocked him face down on the deck. He was able to get out of the boat unassisted. The force of the explosion blew the engine hatch covers out of the boat. The occupants that were standing on the covers were thrown upward and came down in the engine compartment. One occupant landed back down across the starboard engine. The other occupant landed on the outboard side of the port engine. He was helped out of the boat by the marina attendant. The occupant that was in the process of boarding fell in the water between the dock and the starboard side of the boat. The occupant that was holding the boat was thrown back onto the dock. After the explosion, the aft half of the boat and entire bilge was ablaze with flame heights extending approximately two feet above the deck. The fire was extinguished within ten minutes after the explosion by a large dry powder type fire extinguisher that was located on the fueling dock. The boat was declared a total loss by the insurance company. At the time of the investigation, the occupant that was standing on the port engine hatch cover was still hospitalized and had lost nine toes as a result of the fire.

1.0 BOAT OCCUPANT DATA

Occupants	Sex	Age	Weight	Swimming Ability	Boating Experience	Formal Boating Instructions	PFDs Worn
(1)Operator	M	69	165	Good	>500 hrs	Pwr. Sqd.	No
(2) Passenger	M	71	150	Good	>500 hrs	None	No
(3) Passenger	M	31	190	Good	unknown	Unknown	No
(4) Passenger	M	76	140	Good	>500 hrs	Taught Pwr.Sqd. Course	No
(5) Passenger	M	52	170	Good	<200 hrs	None	No

1.1 Co-Owner/Operator

The operator was a college graduate and the president of a seemingly very prosperous insurance company. He had owned and operated I/O boats under 30 ft in length for the past 15 years. He had completed the Power Squadron boating safety course and seemed to have an average knowledge concerning boat operations. Considering the confusion that must have prevailed immediately after the explosion, his recall of events concerning the accident was very descriptive. Very little direct questioning by the investigators was necessary to obtain the details of the accident.

1.2 Passengers

No. 2 - He was a college graduate and a practicing lawyer. He had owned and operated various outboard and inboard boats for 35 years. He seemed to be very cautious concerning boating safety procedures. Any time he was aboard the involved boat, he insisted that he be responsible for fueling.

No. 3 - He was a college graduate and worked as the manager of a real estate company. He was hospitalized in serious condition at the time of the investigation and could not be interviewed. His boating experience was unknown; however, the operator stated that it was the first time he had been aboard the involved boat.

No. 4 - He was not available for interview, but according to the occupants interviewed, he was a college graduate and the owner of a real estate agency. He had owned and operated various types of outboard and inboard boats during the past 40 years. He was a former Power Squadron Course instructor.

No. 5 - He was a high school graduate and worked as the office manager of an insurance firm. He had operated inboard/outdrive boats during the past five years including the involved boat. His description of the accident details was very similar to the account given by the operator.

2.0 ENVIRONMENT

The sky was clear and the visibility was excellent. The recorded air temperature was 70°F and the recorded water temperature 65°F. The wind was from the southeast at 5-10 mph and the water was calm.

3.0 NARRATIVE DESCRIPTION OF ACCIDENT

3.1 Pre-Accident

The involved boat was owned by six businessmen, each having one-sixth ownership. Only two of the co-owners were aboard at the time of the accident, the operator (1) and passenger (4). Except for passenger (3), the occupants had fished together for a number of years. Passenger (3) was well known by the other occupants but had never been on an outing with them.

During a week in early December, 1975, the fishing trip was planned for mid-December, 1975. On the day before the accident, the men traveled approximately 40 miles by automobile to the marina where the involved boat was kept. The fishing gear and supplies were loaded aboard the boat, and the party traveled approximately 30 miles down inland waterways to a fishing camp located near the gulf of Mexico in southern Louisiana. On fishing trips, the involved boat was used only for transportation to and from the fishing camp. The fishing was done from skiffs supplied by the fishing camp operator.

After arriving at the camp, the men fished the remainder of the day and spent the night in a cabin on the camp grounds. The next day, the men arose early and fished until approximately 1000. The men returned to the involved boat and started making preparations for the return trip to the marina. According to the operator, the engine hatch covers were removed and the forward and aft bilge blowers turned on and the engine compartment and bilge allowed to vent for approximately 10 minutes. The occupants did not detect any fuel vapors during the venting operation and did not see any liquid in the bilge. Although there was no visible liquid in the bilge, the operator turned on the bilge pump to insure that the bilge was free of water (his normal start up procedure). No liquid was pumped out. The engine cover hatches were secured and the blowers turned off. The gear and fish were loaded aboard, and the party got underway back to the marina at approximately 1025. The party arrived at the marina fueling dock at approximately 1135. The marina owner told the investigators that his policy was for owner/operators to fuel their own boats, because he did not want to accept the liability responsibility in case of an accident.

All occupants got out of the boat onto the dock, and (5) secured the boat to the dock by the bow line. (2) started the fueling operation, and the other occupants went inside the marina office and bar located a few yards away. While the boat was being fueled by (2), the other occupants talked to the marina operator and milled around inside. According to (2), 44 gallons of fuel were put in the 150 gallon tank which brought the level up to approximately 148 gallons. He stated that he always filled the tank a couple of gallons short of the full level so fuel would not overflow from the fill hose which sometimes occurs when tanks are completely topped off. When the fuel nozzle was removed from the fill hose, a small amount of fuel came out of the nozzle and ran down the starboard side of the boat (exterior). (2) secured the fuel fill cap and washed the fuel off the starboard side with a dock side water hose.

3.2 Accident

Gear and people aboard were approximately as shown in Figure 1, and the weather as in Section 2.0.

At approximately 1150, the occupants started boarding in preparation to move the involved boat across a narrow channel to the slip where the boat was kept. All the occupants were to make the short trip by boat, because their automobile was parked near the slip and it was a considerable distance by land to a channel crossing. According to the operator, passengers and witnesses, three of the occupants had boarded when a violent explosion occurred in the bilge. Location of the operator and passengers was as follows:

Operator (1) - Getting into the operator position behind the steering wheel at the helm station.

Passenger (2) - Standing on the starboard engine hatch cover.

Passenger (3) - Standing on the port engine hatch cover.

Passenger (4) - In the process of boarding - one foot on the starboard gunwale and one foot on the dock.

Passenger (5) - Holding to starboard rail with both feet on dock. Waiting to push boat off after engines were started.

The operator stated that the explosion occurred before he had made any attempt to start the engines. It was normal operating procedure for him to turn the forward and aft bilge blowers on prior to fueling the boat. He stated that the blowers were on at the time of the explosion. Action on the part of the operator and passengers immediately after the explosion was as follows:

Operator (1) - He was hit in the back and neck by an unknown object which knocked him face down on the deck on the left side of the helm seat. As he started to get to his feet, he heard (5) yell to him that the boat was on fire and to get out. He got to his feet facing forward, turned around, and noticed that the aft one-half section of the boat was engulfed in flames extending approximately

two feet above the deck. He made his way through the flames and around and over items that had been strewn about on the deck and exited the boat at amidship on the starboard side onto the dock. After he was on the dock, he noticed that one of the passengers was apparently stuck between the port engine and port gunwale. He went back on the boat and attempted to pull the passenger to safety. The heat was so intense that he abandoned the rescue effort and got back onto the dock.

Passenger (2) - The force of the explosion blew the starboard hatch cover and (2) straight up from the boat deck. The hatch cover came down in the water on the port side of the boat. (2) came to rest back down across the starboard engine. He managed to climb out on the dock unassisted.

Passenger (3) - The port engine hatch cover that he was standing on was blown over the port side into the water. He came to rest between the port engine and the port gunwale. His legs were caught under the forward section of the port engine and he was unable to free himself. While the operator was attempting to rescue him, a marina attendant started aboard to assist, but the boat suddenly moved out from the dock and he fell in the water on the starboard side. He pulled himself back on the dock, went aboard and pulled (3) to the dock. The marina attendant was probably able to make the rescue because his clothing was wet and by the time he got aboard, the marina owner had started discharging a fire extinguisher on him, (2), and the aft section of the boat.

Passenger (4) - The force of the explosion caused him to fall into the water between the boat and the dock. He was helped onto the dock by (5) and the marina attendant.

Passenger (5) - The force of the explosion blew him backward to a sitting position a few feet from the boat. He was able to immediately return to the boat and tell the operator to get out.

At the time of the explosion, the marina owner and attendant were inside. The force of the explosion broke out the dock side marina windows and ripped down sections of the interior ceiling. After the marina operator realized what had happened, he grabbed a small fire extinguisher that was hanging on the wall inside the marina, went outside and attempted to extinguish the boat fire. The attendant went outside with the owner and fell in the water while trying to board the boat to rescue (3). When he did board the boat, the marina owner directed the fire extinguisher on him and (3), which prevented him from receiving severe burns while he pulled (3) to safety. After exhausting the small extinguisher, the marina owner went back inside the office and grabbed two medium extinguishers as shown in Photograph 1. These two extinguishers were exhausted and were not sufficient to extinguish the fire. The attendant used a large dock side extinguisher (see Photographs 2 and 3) to extinguish the fire.

After the fire was extinguished, a local parish sheriff went aboard and cut the electrical wiring connected to the battery to prevent any electrical shorting. See Photographs 4 and 5.

Injuries sustained as a result of the explosion and subsequent fire were as follows:

Operator (1) - Minor burns on hands, arms and face. Minor cuts and bruises on face, back of neck and shoulders.

Passenger (2) - Minor burns on back, arms and face. Minor cuts and bruises on back and arms

Passenger (3) - Severe burns on legs and feet and a fractured cheek bone. At the time of the investigation, nine of his toes had been amputated.

Passenger (4) - Broken ankle and minor burns on arms and face.

Passenger (5) - Minor burns on face and hands.

According to the occupants and witnesses, none of the people aboard had been drinking on the day of the accident.

Refer to Photographs 6, 7, 8, and Figure 1 for accident area.

Time Sequence

1025	Left fishing camp for marina.
1135	Arrived at marina fueling dock and occupants got off boat.
1137	(2) started fueling boat.
1145	(2) completed the fueling and wash-down operation.
1150	Occupants started boarding and explosion occurred.
1150-1151	Operator exited boat and went back aboard and attempted to rescue (3).
1151-1153	Marina attendant went aboard and pulled (3) from the burning boat, and marina owner started discharging fire extinguisher into aft section of boat.
1153-1200	Marina owner and attendant extinguished the fire.
1200-1205	Local parish sheriff went aboard and cut all electrical wiring to battery.

4.0 FACTS FROM THE BOAT INSPECTION

The boat was a fiberglass 1971 Model Seabird I/O powered by two 215 horsepower Mercury engines. According to the operator, new engines had been installed approximately three months before the accident. The overall length was 28 ft with a maximum beam of 10 feet.

It was evident from the visual examination that the explosion was of high intensity and the combustion area probably covered the entire bilge. The deck was cracked or torn loose from the hull side around the entire boat. Permanently installed items such as storage cabinets, table, seats, etc. were torn loose from the deck and scattered around the interior. The cabin top had been torn loose from the sides and the starboard side had dropped down inside the passenger compartment. The fire damage was minor compared to the destruction caused by the force of the explosion. The engines appeared to be in reasonably good condition. No evidence of fuel leakage could be found on any of the fuel lines or fittings. The 150 gallon fuel tank was located on the boat centerline approximately four feet forward of the engines. The tank was full of fuel and no leaks were found. The electrical insulation on the wiring in the bilge area was badly burned. Some of the insulation damage could have been caused by electrical shorts which probably occurred after the explosion. Two small blowers were installed in the bilge, one in the engine compartment on the starboard side and one forward of the fuel tank. A fuel vapor detector sensor was installed in the bilge near the aft starboard corner of the fuel tank. The sensor was badly charred and one corner was missing. Post accident boat interior and exterior are shown in Photographs 9 through 19. Refer to Photographs 20 and 21 for engine hatch covers.

5.0 PSYCHOLOGICAL AND HUMAN FACTORS

The occupants of the involved boat were well educated men with at least an average knowledge concerning operation of boats in this class. As far as could be determined, they always went through the proper safety checks prior to start up; however, the safety procedures were not followed immediately prior to the accident. Possibly the safety check was deleted due to the following:

(1) A considerable amount of gear and supplies as shown in Figure 2 was on and around the engine hatch covers. In order to raise the hatches to inspect the engine compartment, the gear and supplies would have had to be moved.

(2) No fuel vapors had ever been detected in the engine compartment or bilge.

(3) A fuel vapor detector was installed in the bilge.

(4) The engines had been running properly a short time before the accident. Also, the bilge had been inspected less than two hours before the accident.

(5) The boat was to be moved only a short distance across the channel to the slip.

According to the operator, he always turned on the bilge blowers prior to the fueling operation. He was not aware that all electrical equipment should be turned off prior to fueling.

The following statements are strictly opinions formed by the investigators and may have little or no relevance concerning this accident.

It seemed from the interview that the operator was a very influential and respected person in his social and business circle. It seemed that he was the type individual that rarely (admittedly) made a mistake and might rationalize any mistake that could affect his stature. His recall of events prior to the accident could have been influenced by his reluctance to accept the possibility of an error even if one was made.

He stated that he had not attempted to start the engines prior to the accident; however, during examination of the boat, it was observed that the port ignition switch was ON. When he was shown the switch position, he turned it to the off position and told the investigator that the switch should not have been on. He made no further comment on the switch position.

Passenger No. 5, who worked as the office manager for the operator, seemed careful to verify the operator's statements which, in some instances, required him to change his own statements. For instance, No. 5 stated that the blowers were off at the time of the explosion; however, when it was brought to his attention that the operator said they were on, he immediately agreed that the blowers were on.

6.0 PROBABLE CAUSE OF ACCIDENT

The entire fuel system was visually examined for possible fuel leakage points. All fuel lines and hoses were connected and secured except for the fuel fill hose. The flexible fill hose connecting the fuel tank to the starboard side fuel fill deck fitting was disconnected from the deck fitting and had fallen into the bilge. The loose end of the hose was badly deteriorated and a radial crack was found on the deteriorated side immediately above the metal hose clamp. The deck fitting was removed and the hose/fitting reconnected. It appeared that the deck fitting had extended down in the hose to the top of the metal clamp (approximately 3/4 inch), which would account for the radial crack in the hose. Whether the hose was installed improperly (metal clamp tightened around the bottom edge of the deck fitting) or whether the hose had worked loose due to vibration could not be determined. It is likely that the force of the explosion caused the hose/fitting to completely separate. Since this was the only suspect area in the fuel system, it is the opinion of the investigators that the fuel leak occurred at this location. Refer to Photographs 22 through 29 for hose and deck fitting. Fuel leakage at the deck fitting/filler hose connection would have occurred only during fueling, because the connection was higher than any other component of the fuel system. The leaking fuel would have run down the filler hose and into the bilge. The boat construction was such that fuel could have accumulated in the bilge along at least 75 percent of the boat length. The boat had been underway for over an hour prior to the accident; therefore, the engine compartment and bilge temperature was probably sufficiently high to rapidly vaporize some of the leaking fuel to the explosive mixture level. Since there was a significant fire after the explosion, it is assumed that a considerable amount of raw fuel had accumulated in the bilge prior to the explosion.

The ignition source could not be determined. The possible sources are as follow:

- A spark from the starter circuit if the operator attempted to start one of the engines. The operator stated that he did not turn the ignition switch to the start position; however, the port engine ignition switch was on at the time of the investigation. The ignition switch was spring loaded so the switch

would automatically return to the on position when released from the start position. According to the occupants, they did not hear the operator try to start the engine. However, if the operator did attempt starting, the starter noise and explosion could have been simultaneous.

- The operator stated that the bilge blowers were on. The motors in these units are usually not hermetically sealed and could be a possible source of ignition. The engine compartment blower was mounted above deck level under the starboard gunwale. The forward blower could not be located without removing deck and gunwale sections, but it is assumed it was located at approximately the same height as the aft blower.

- The sensing element for the fuel vapor detector was mounted on a transverse deck support above the fuel tank on the starboard side. The sensing element was badly charred and the screen was missing. The unit was a hot element type and the flame arresting screen was not in place, therefore, the unit could have been a possible source of ignition.

Two separate marine surveyors examined the boat and control panel within five days after the accident. According to their report, the control panel switches were in the following positions:

Master Control Panel	Accessory Panel
Ignition switches - Off	Water pump - Off
Cabin lights - Off	Horn/wiper - On
Nav./com. - On	Refrigerator - On
Mast light - On	Charger - On
Bilge Pump - On	2 Spares - On
Bilge blowers - On	Main - On
Running lights - Off	

At the time of the investigation, the switch positions were the same as above except the port engine ignition switch was ON. See Photographs 30 through 34.

Due to the intensity of the explosion and the large combustion area, pressure relief vents most likely would have been of little benefit. The overpressure in the bilge would have no doubt been lower if people and gear had not been on top of the engine hatch covers. If no weight had been holding down the covers, structural damage to the boat would have probably been less.

7.0 DYNAMICS/ANALYSIS OF THE ACCIDENT

The explosion blew the engine hatch covers out of the boat exposing the bilge to the atmosphere which provided oxygen to sustain the fire. Immediately after the explosion, the entire bilge was on fire, which indicates that a considerable amount of raw fuel was in the bilge at this time. The fire was extinguished before the boat structure sustained any major fire damage. Plastic components and electrical wiring in the bilge did sustain severe damage as a result of the fire. Also, see discussion in Section 3.2.

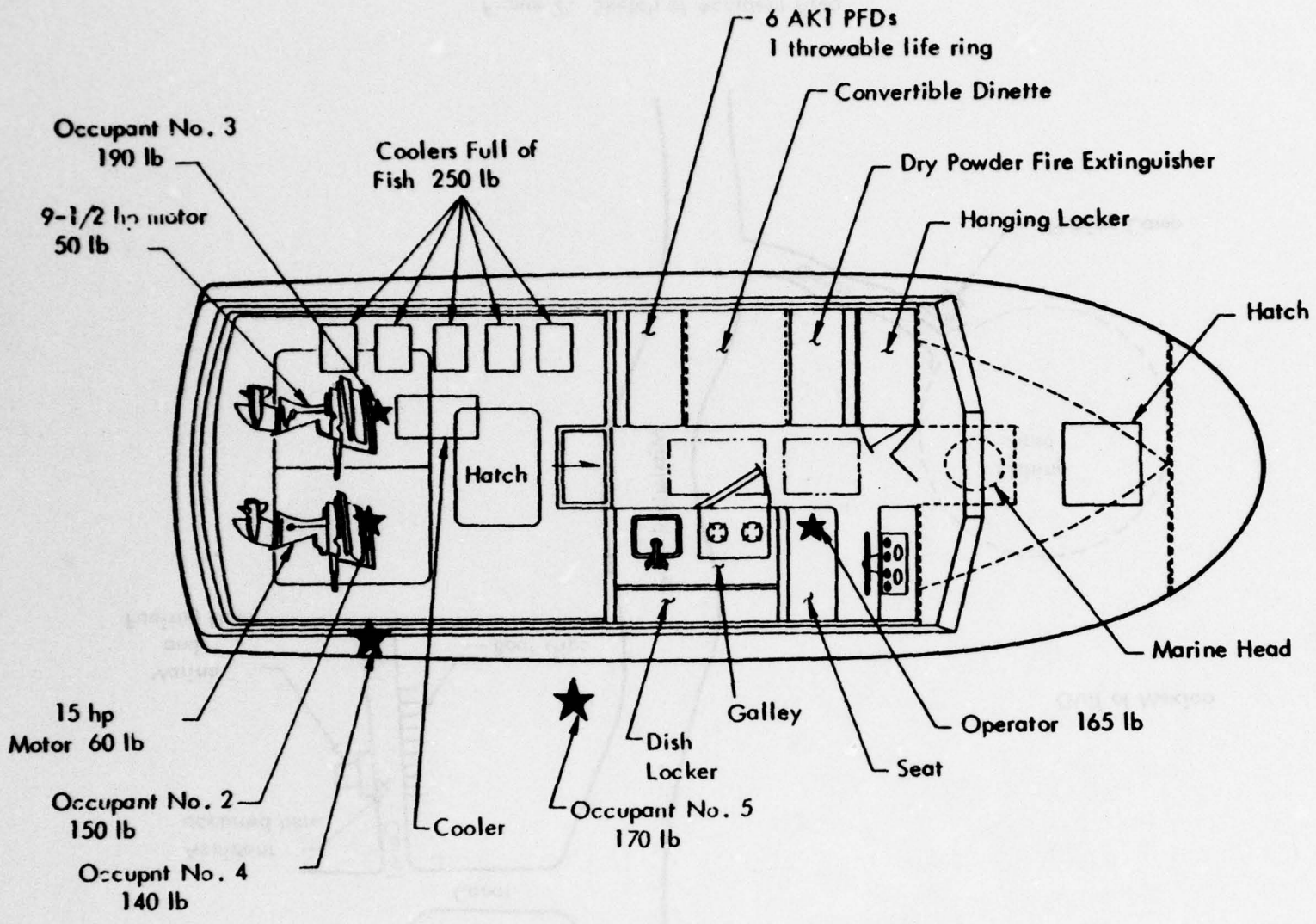


Figure 1. Location of People and Gear At Time of Accident

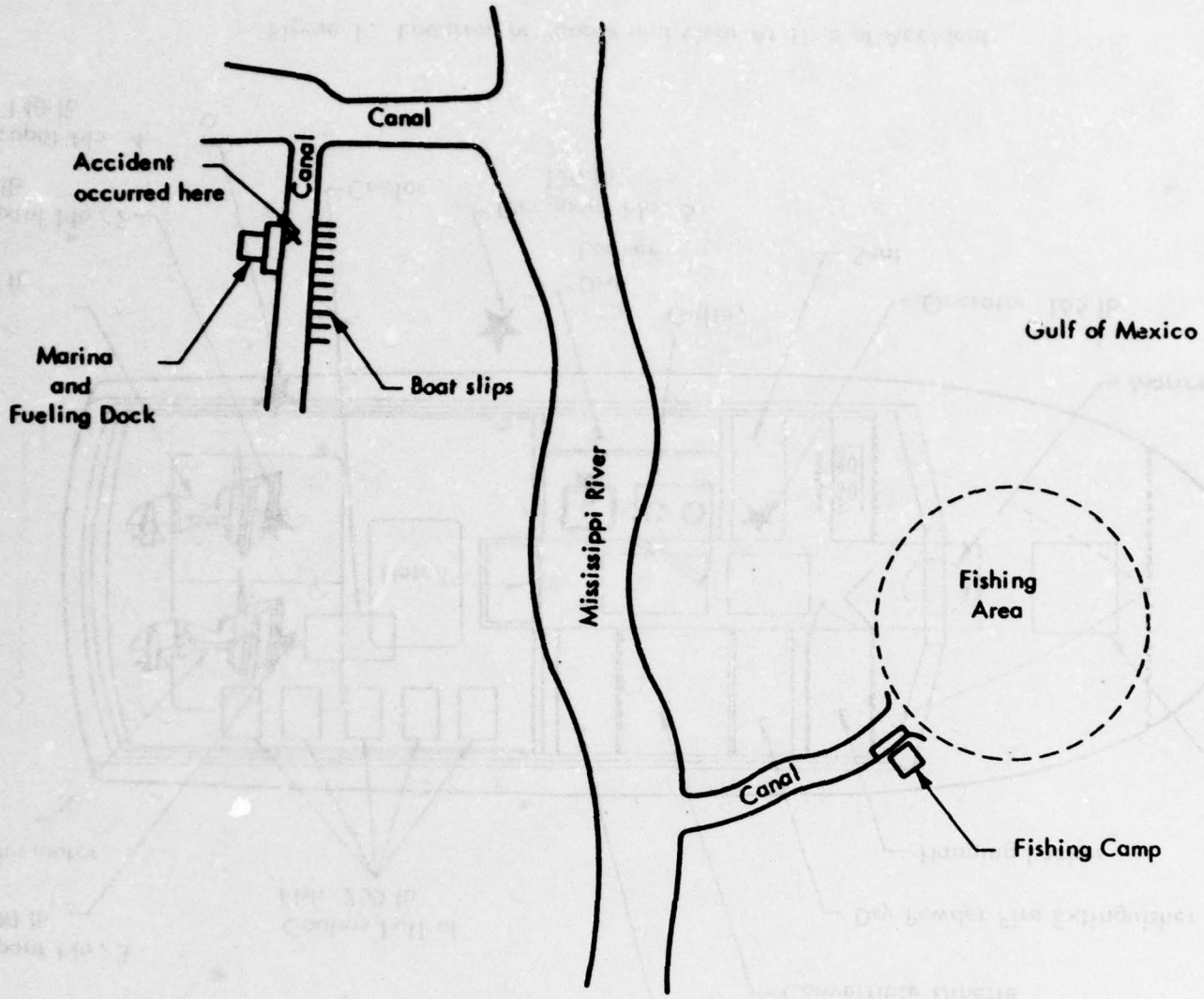
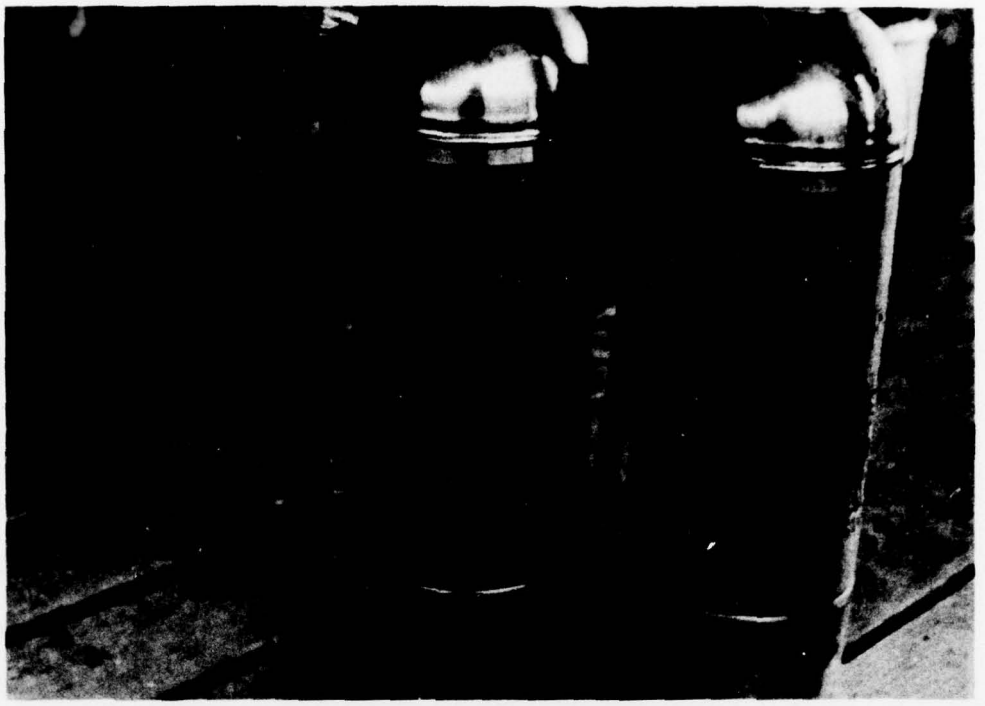
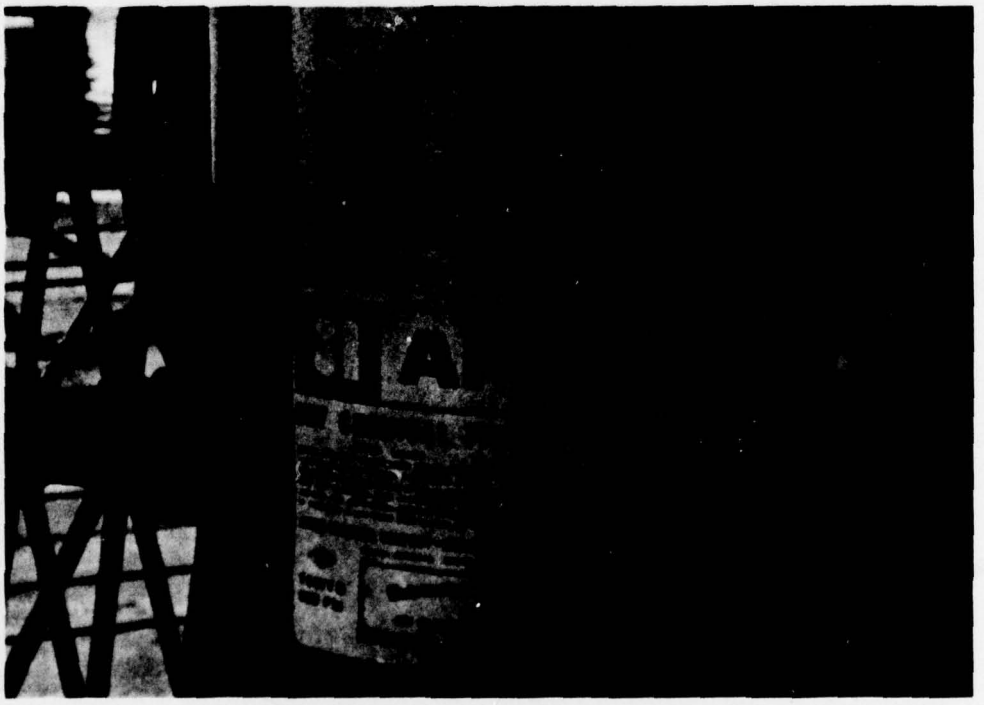


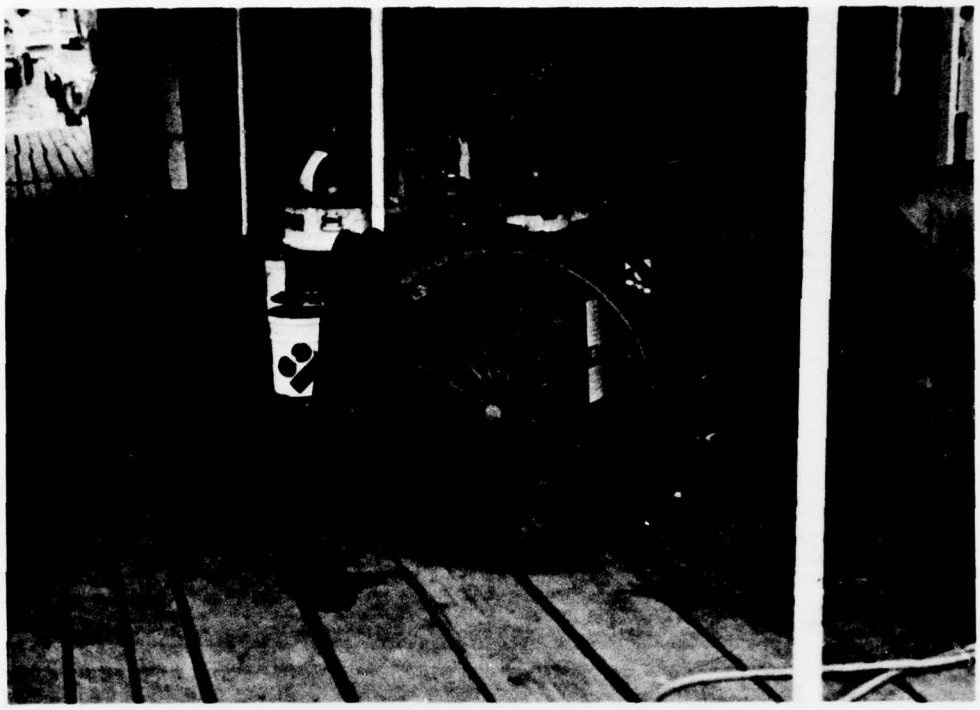
Figure 2. Sketch of Accident Area



Photograph 1.



Photograph 2.



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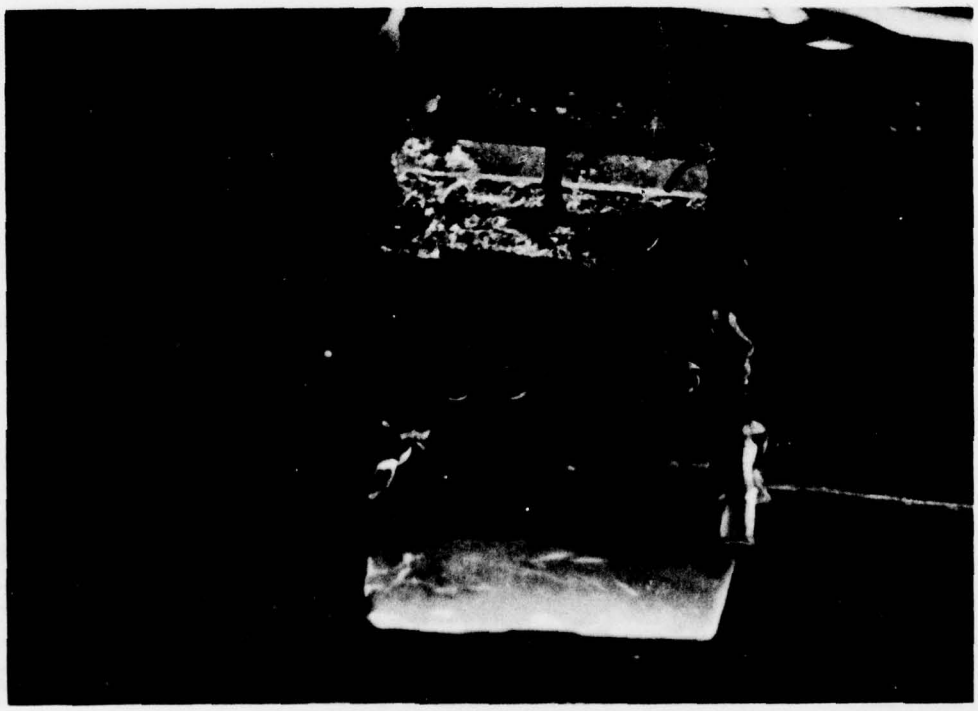

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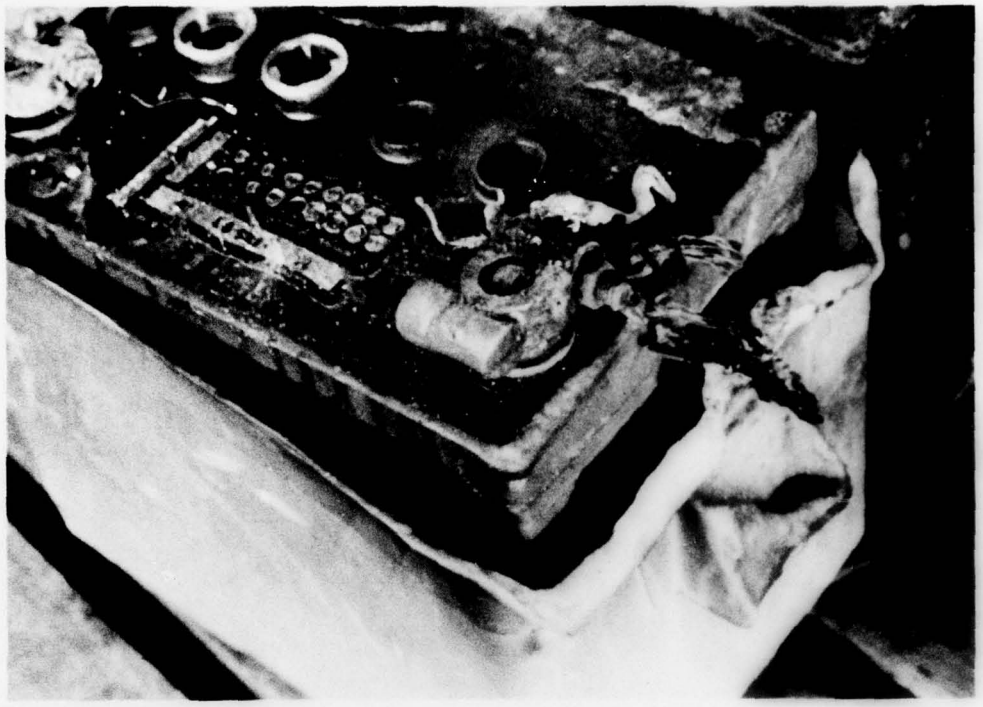
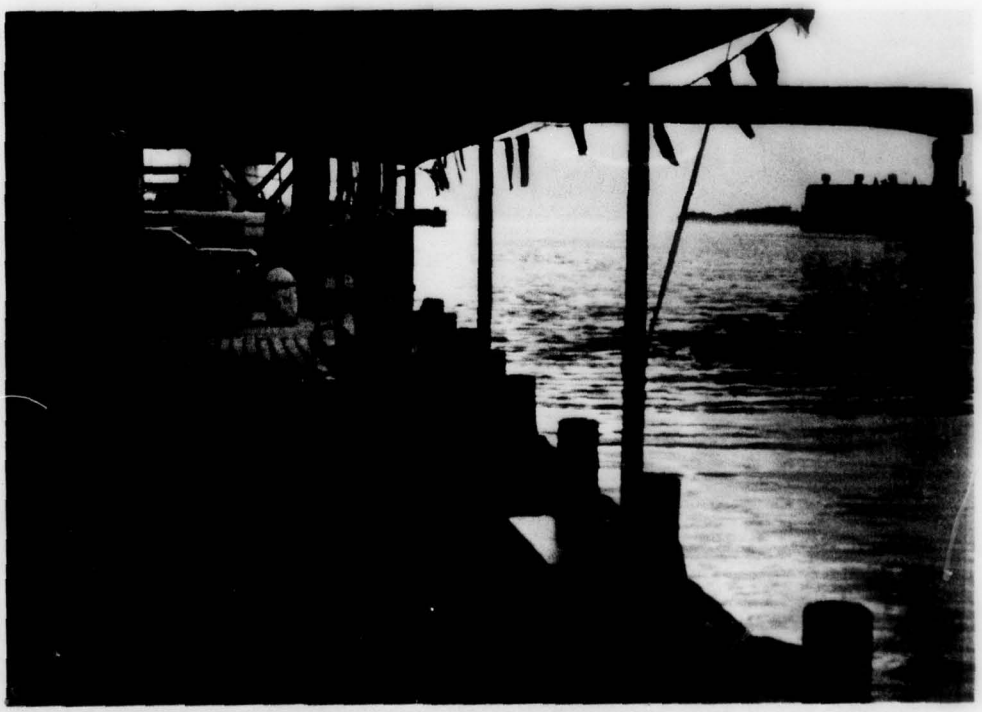
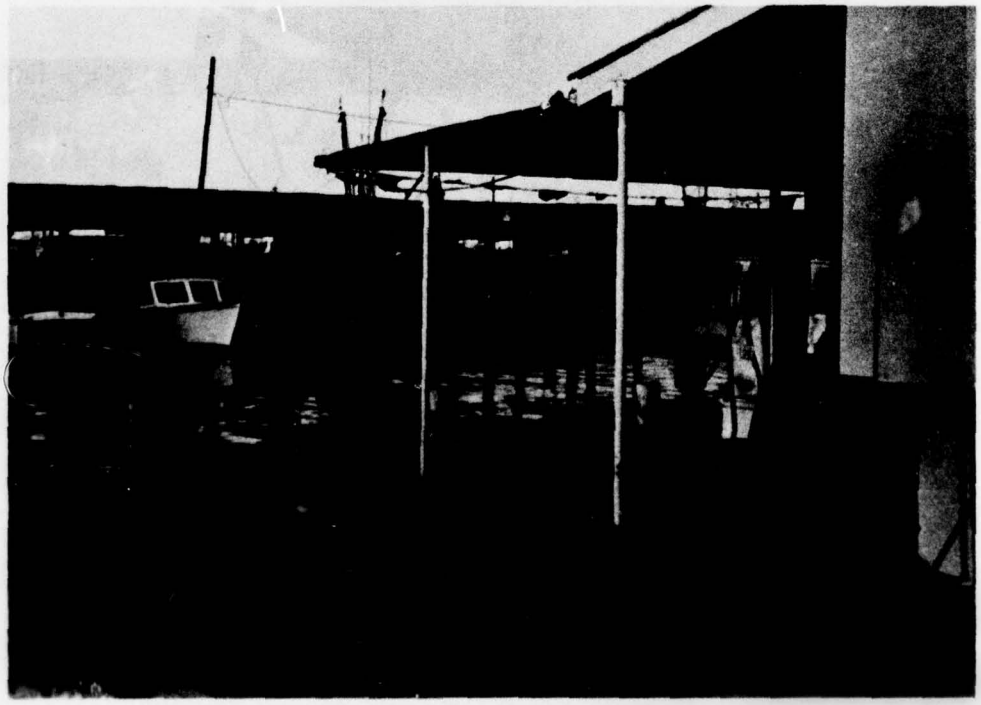


Photograph 5.



Photograph 6.

Photograph 7.



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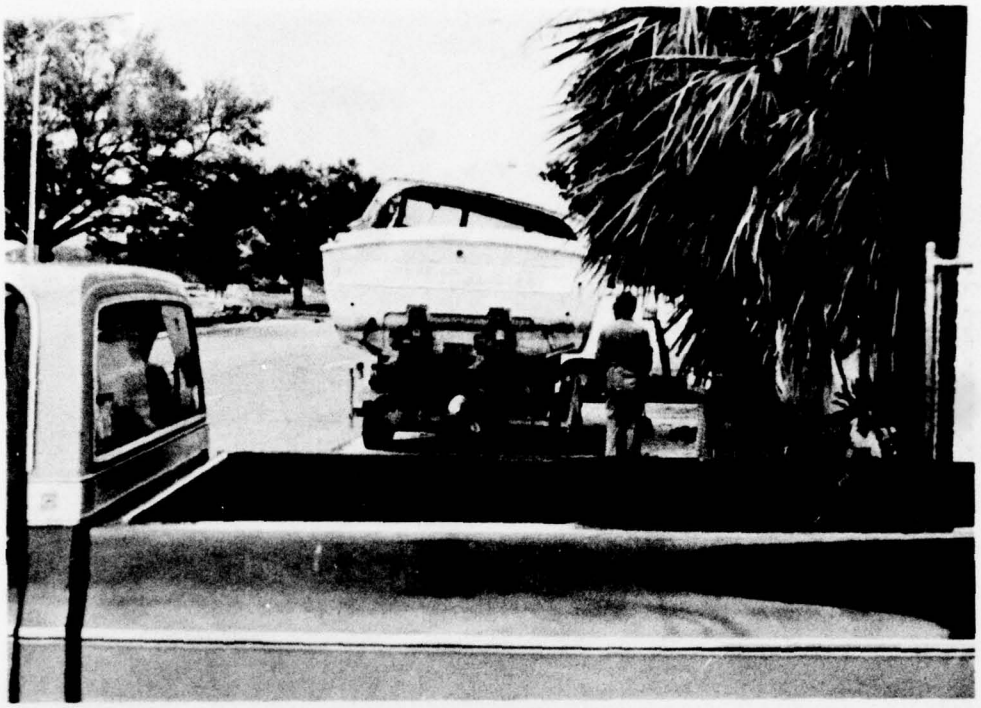

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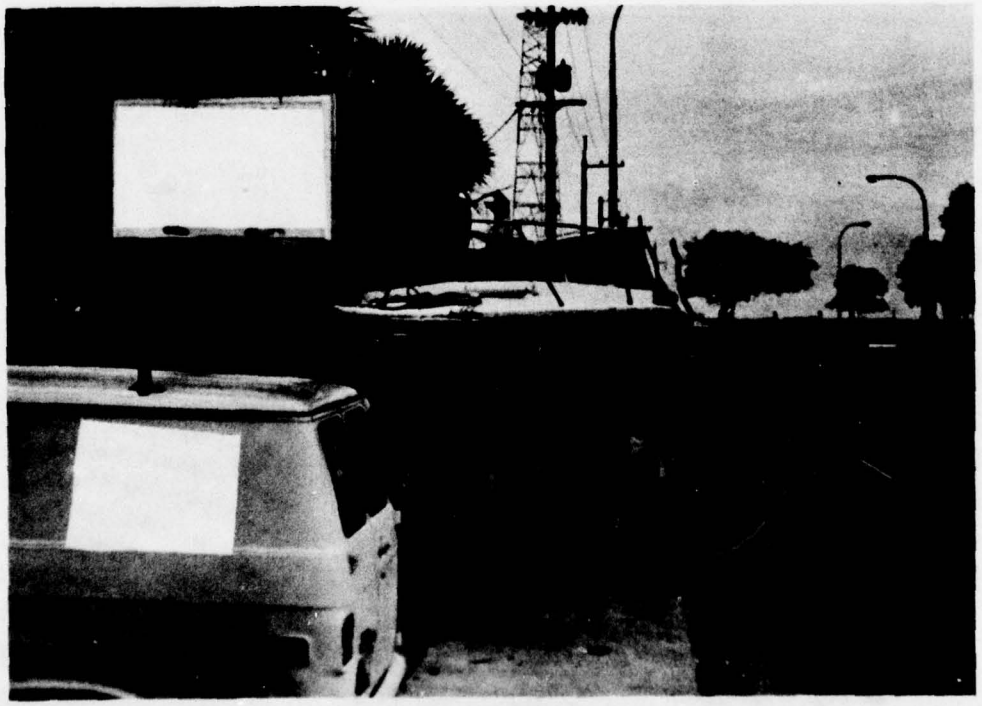

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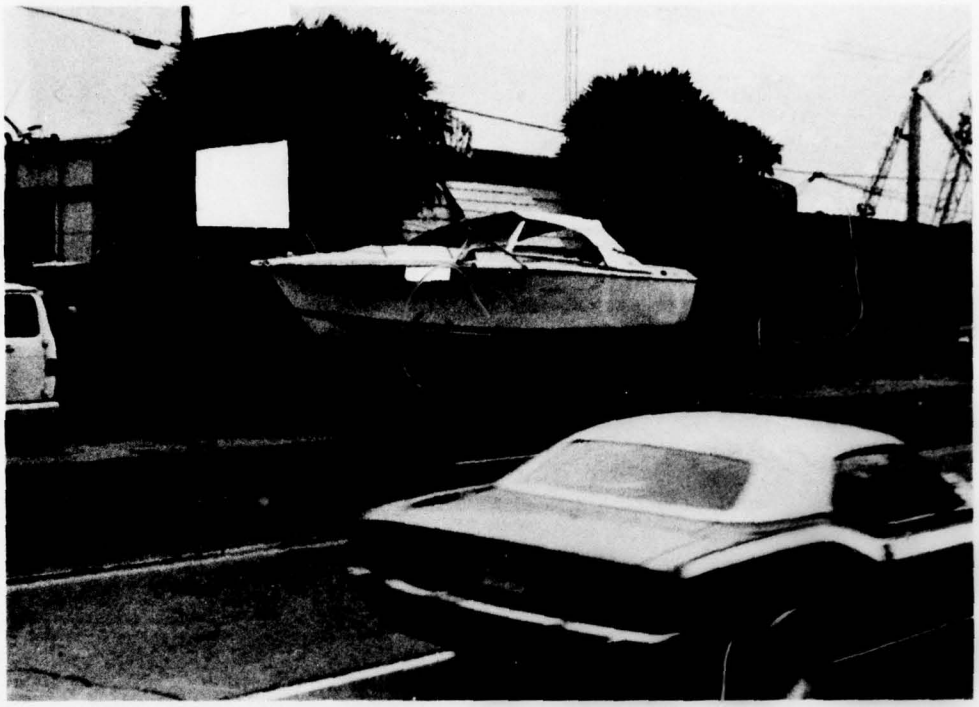

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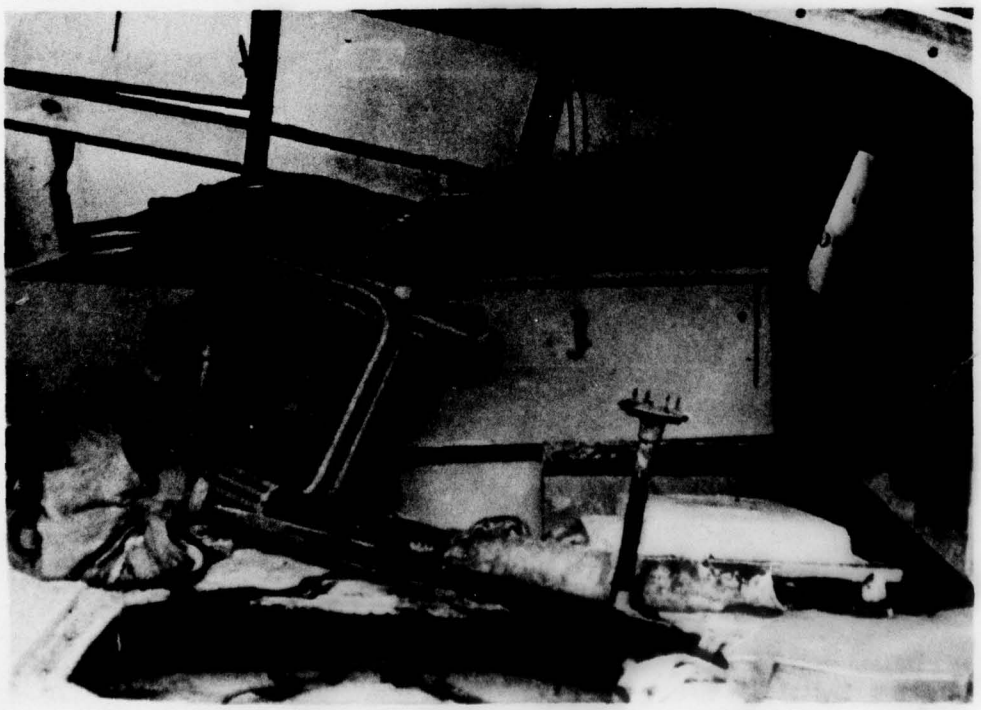

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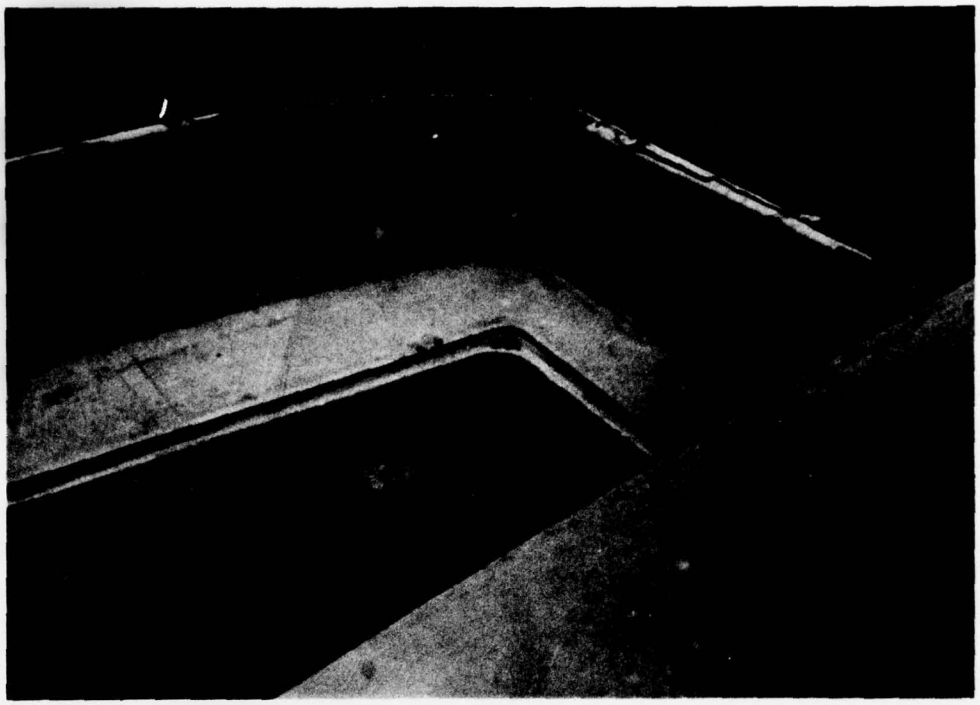

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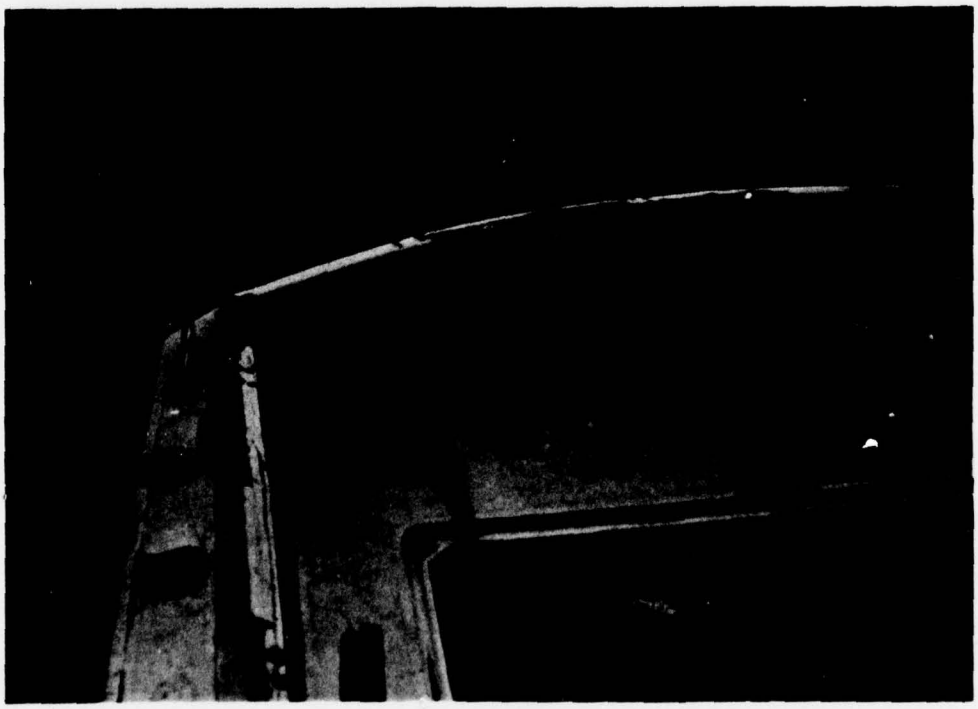

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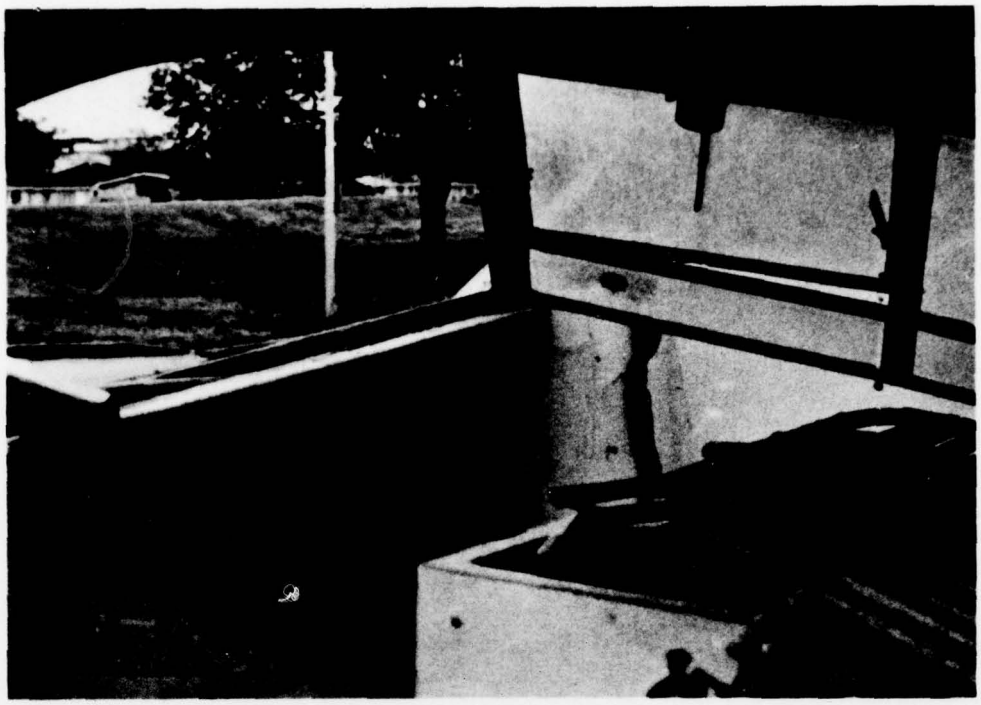
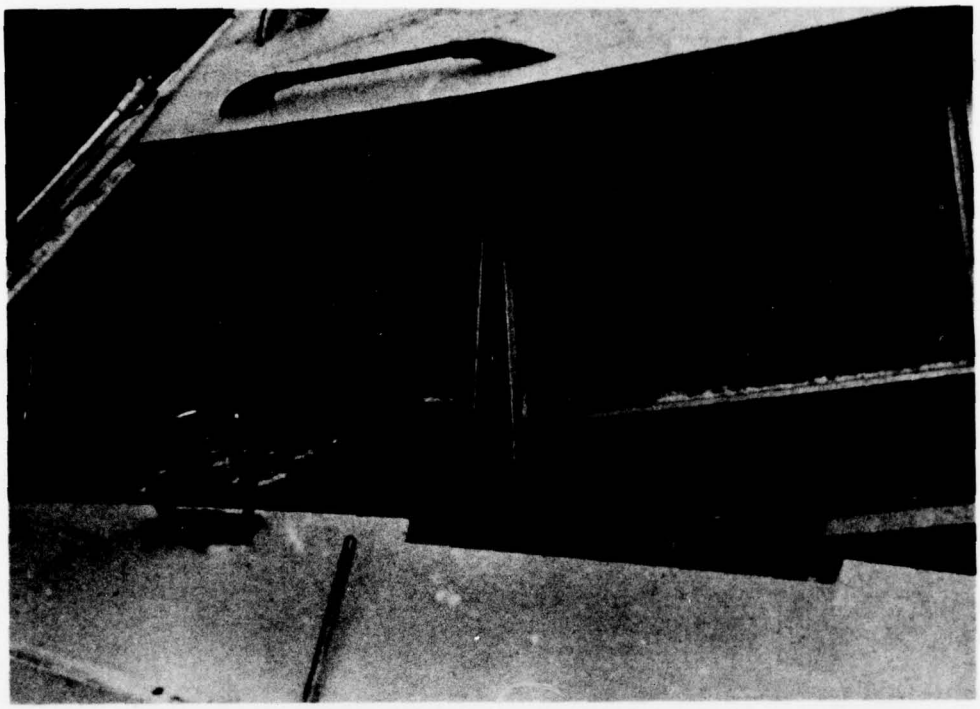


Photograph 15.

Photograph 16.



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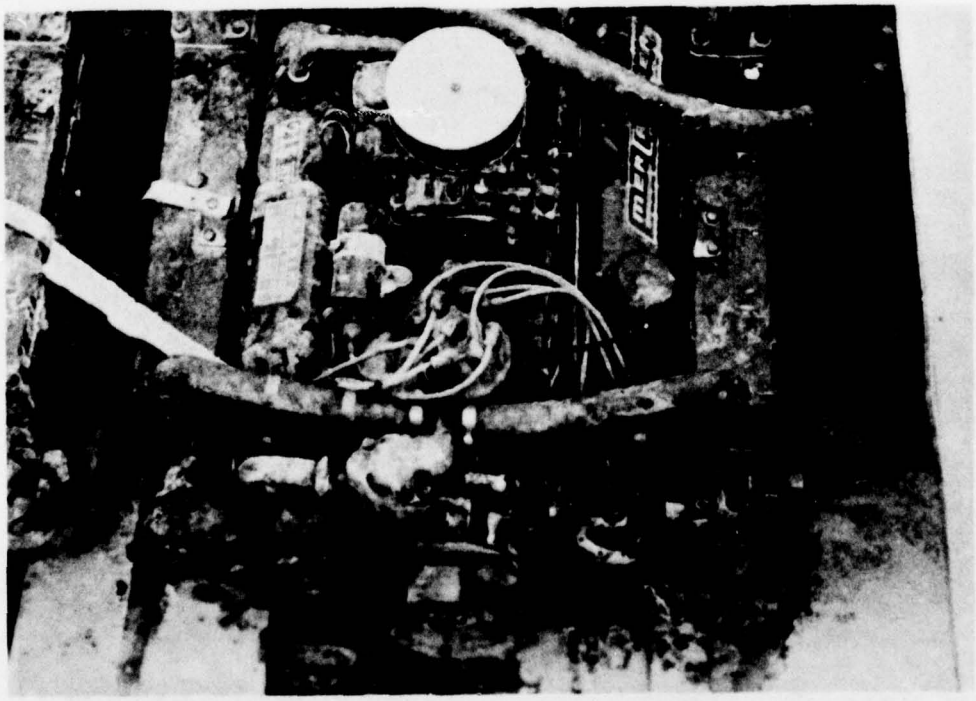

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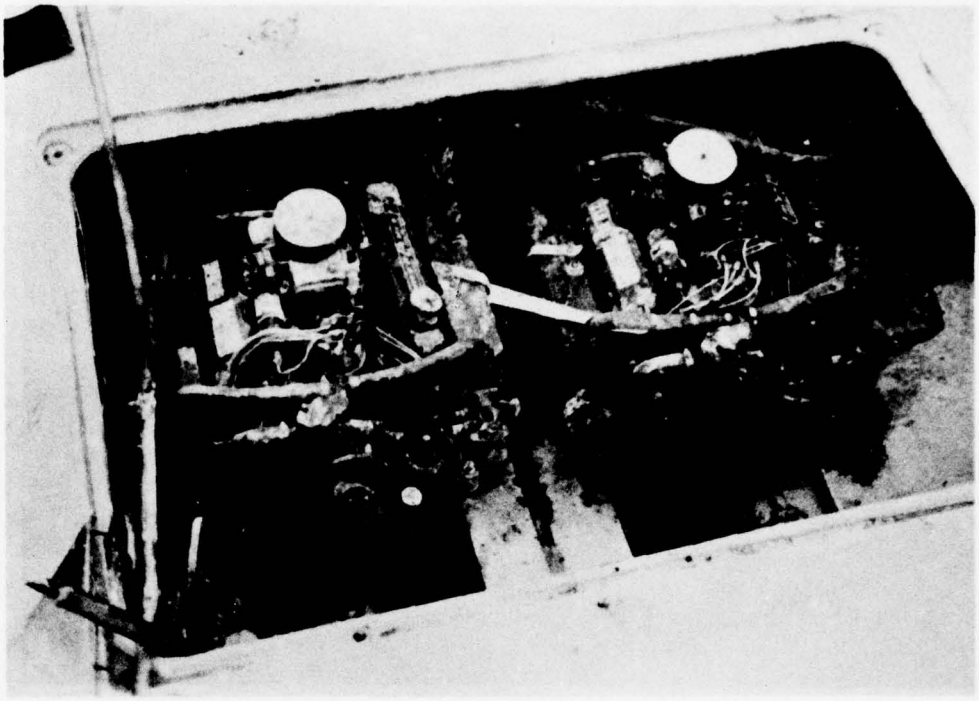

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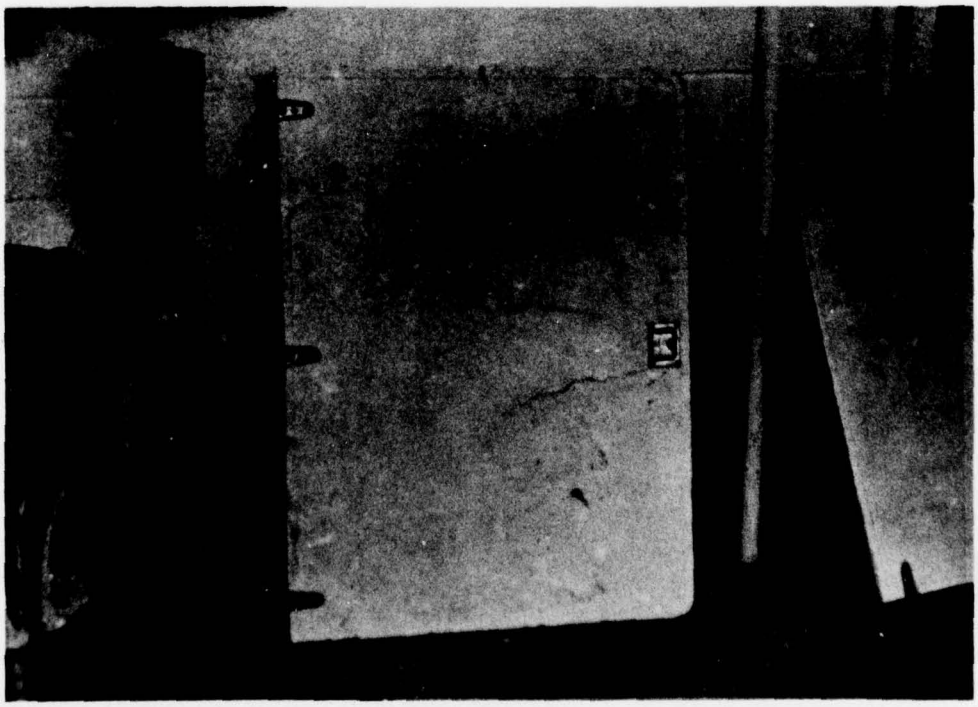
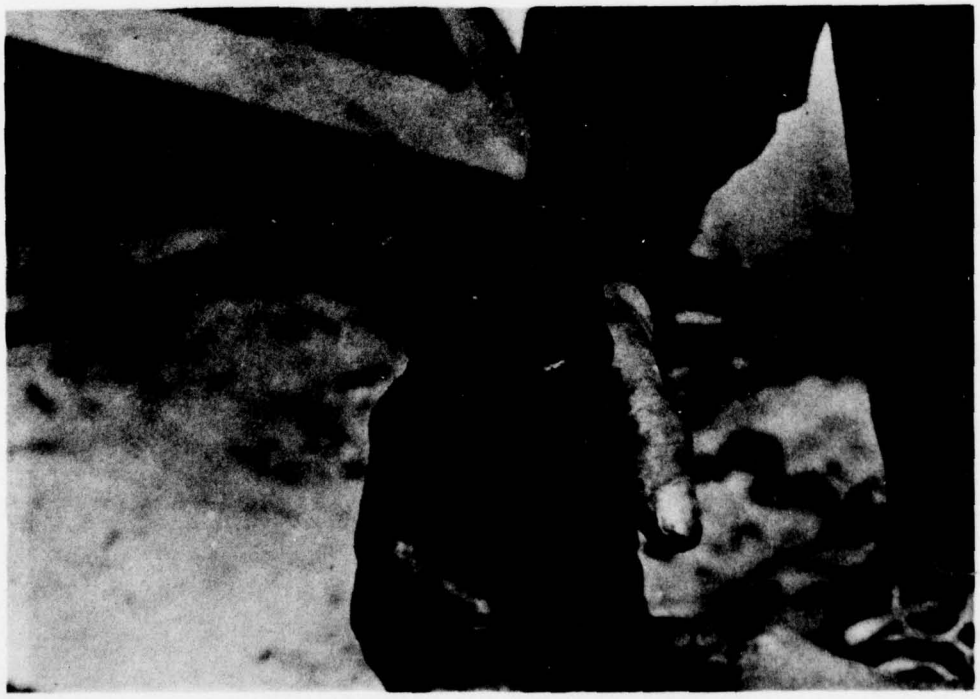


Photograph 20.

Photograph 21.



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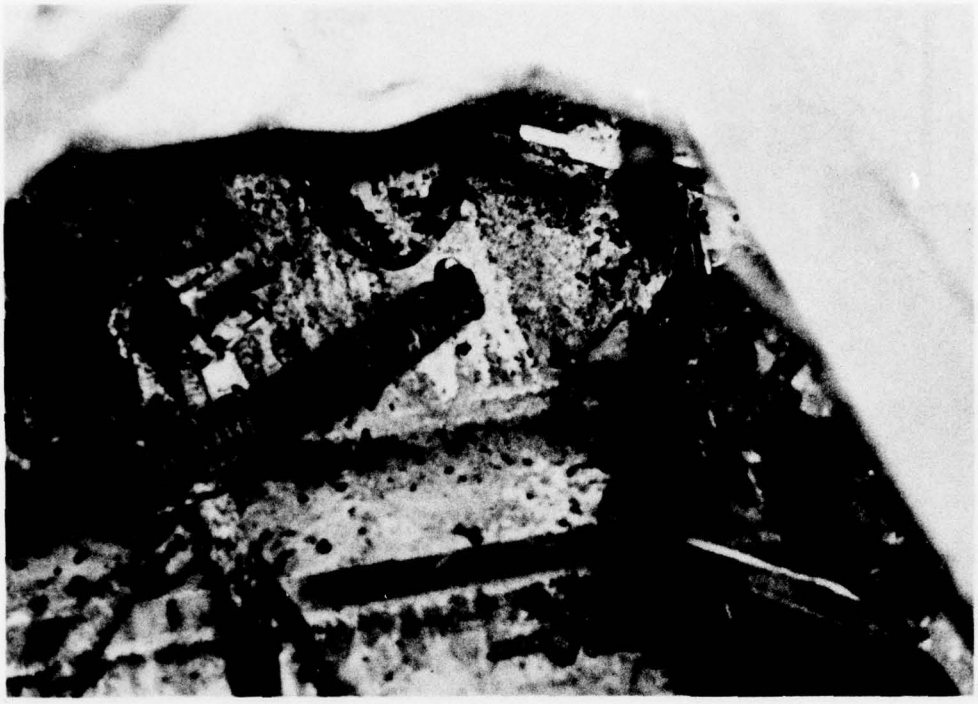

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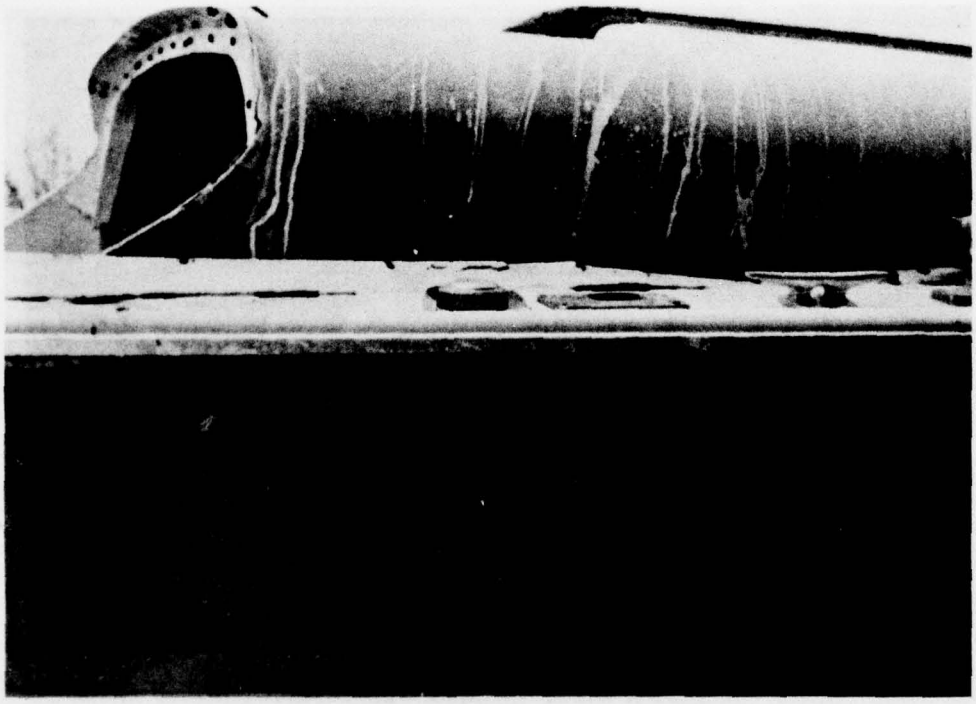

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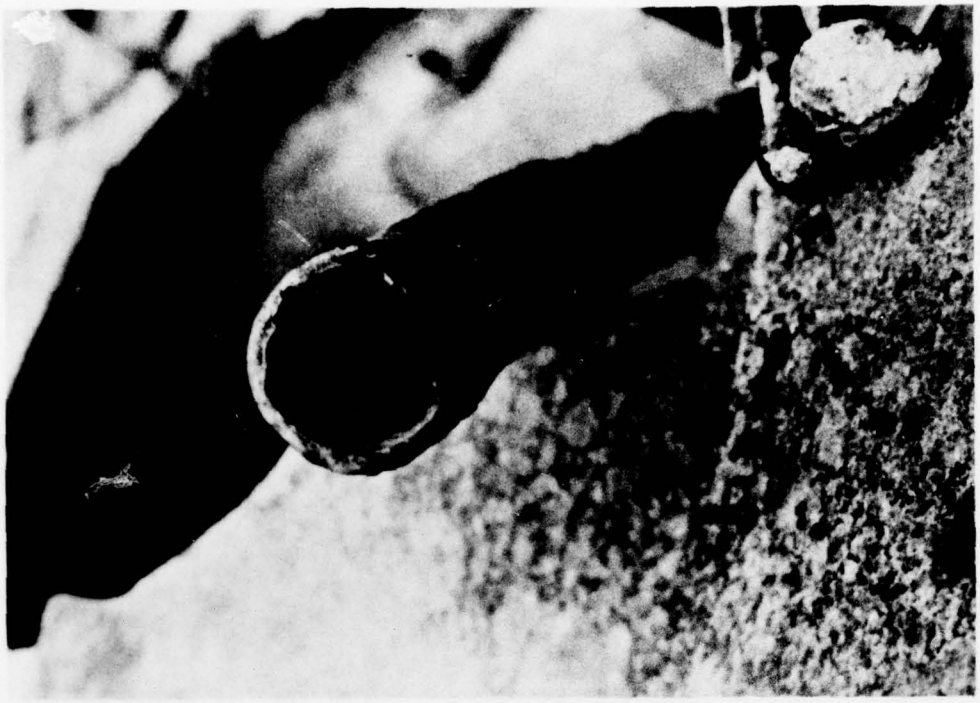

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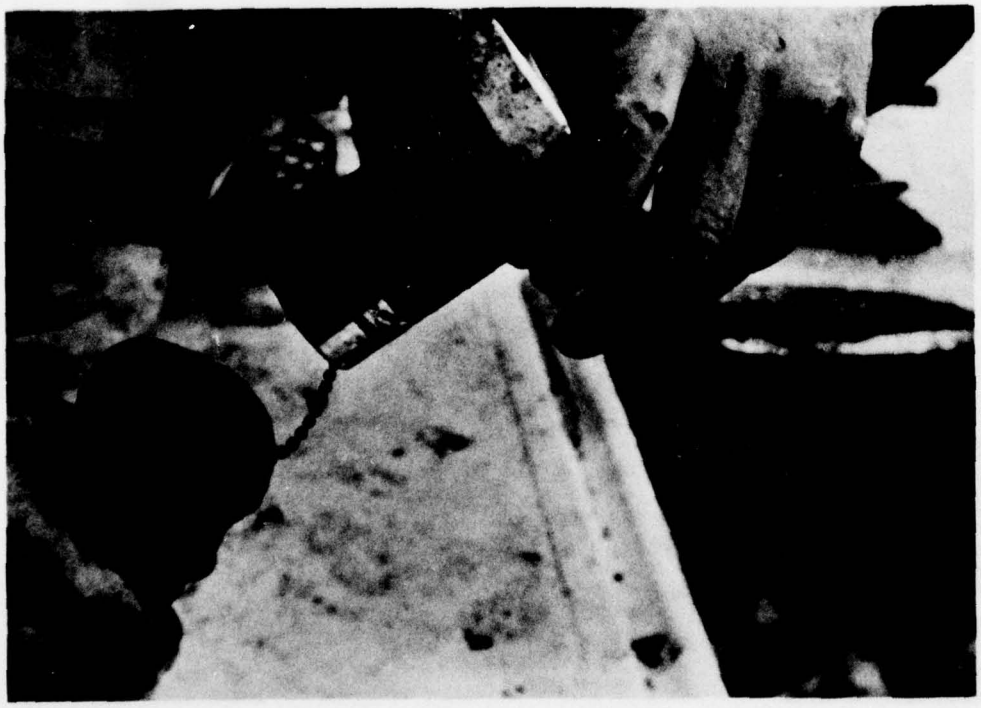

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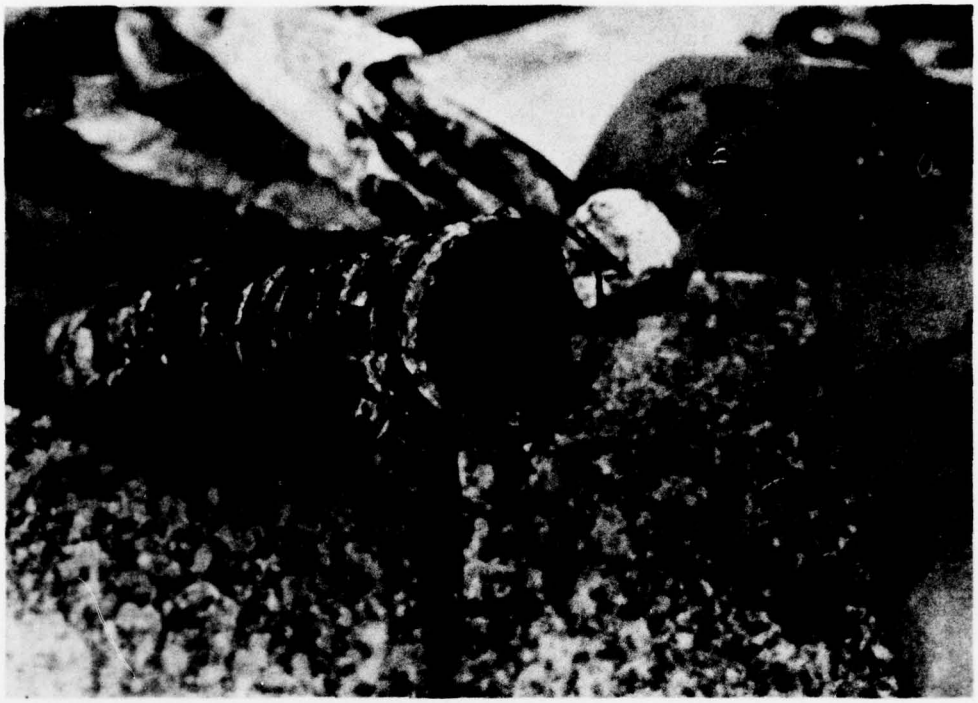

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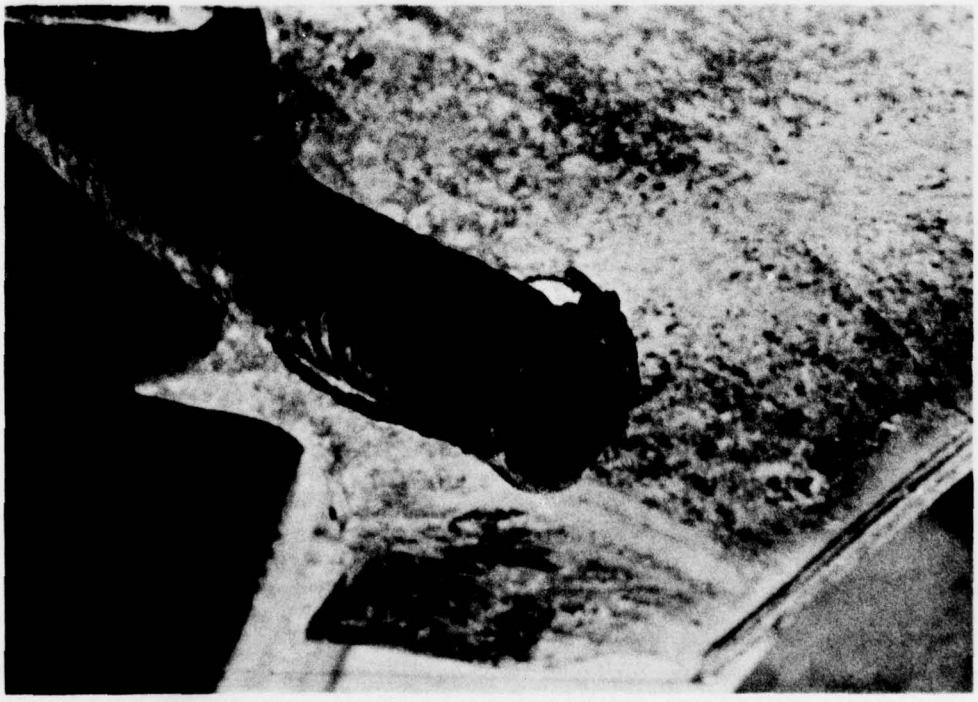
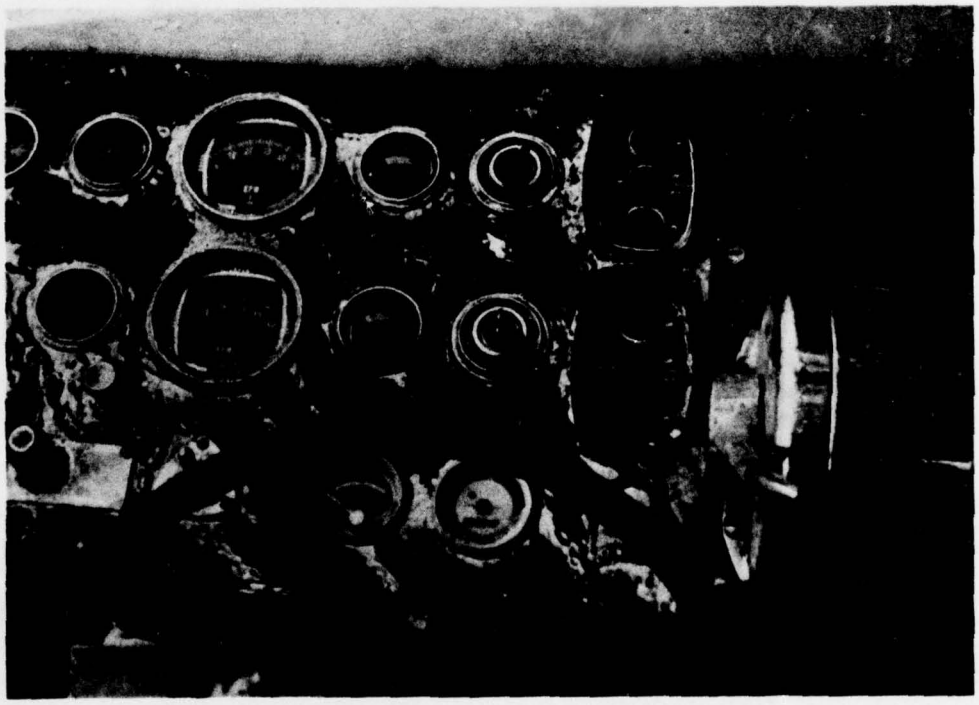


Photograph 28.

Photograph 29.



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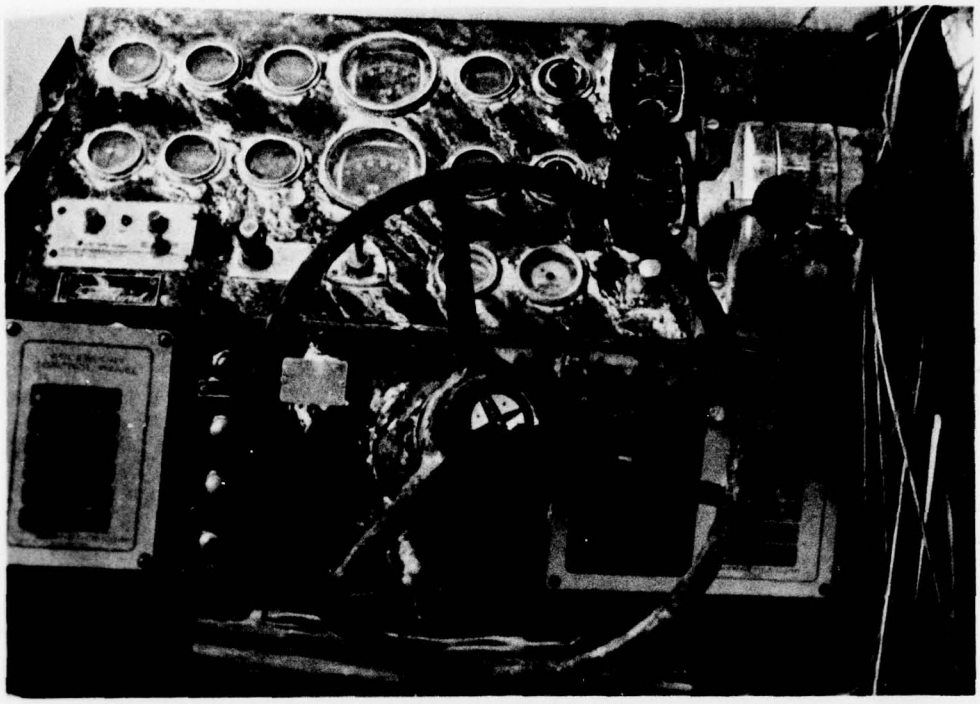

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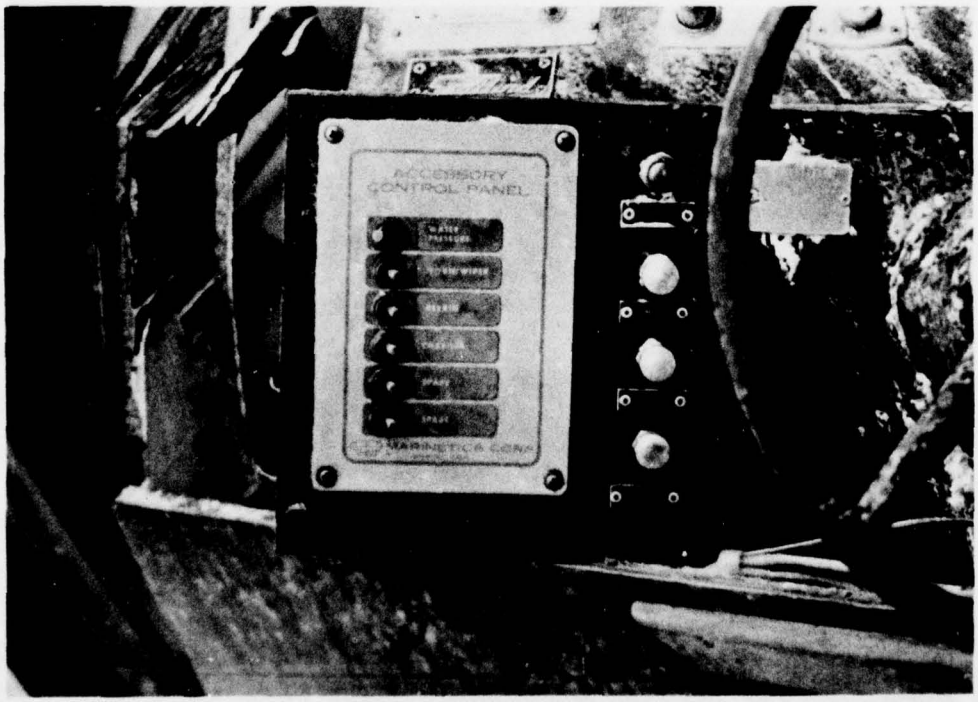

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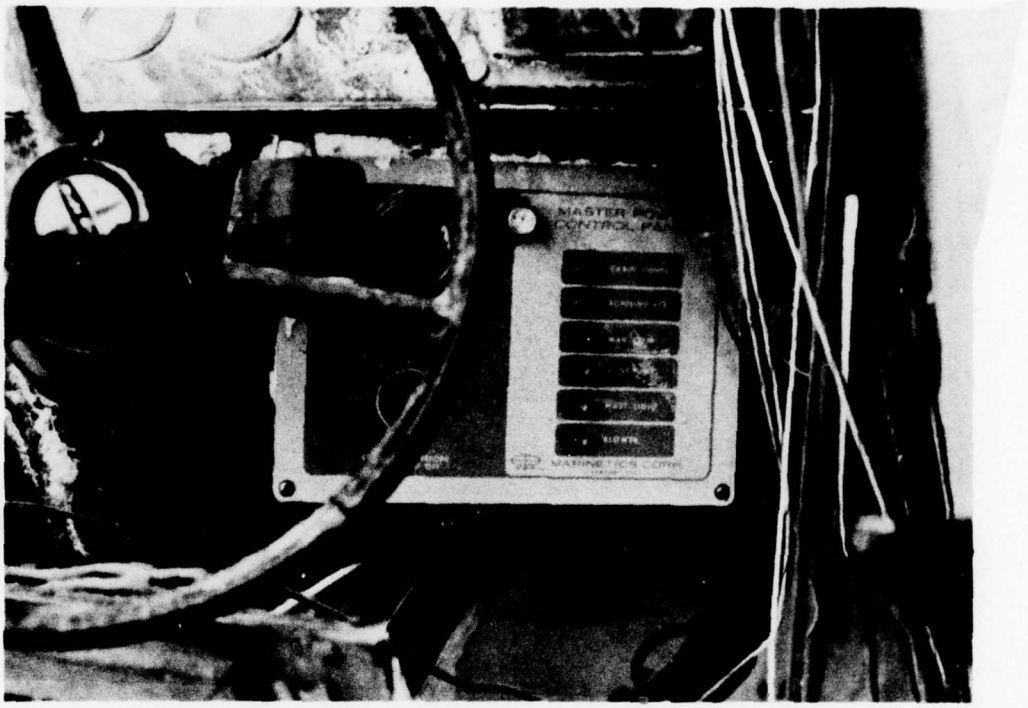

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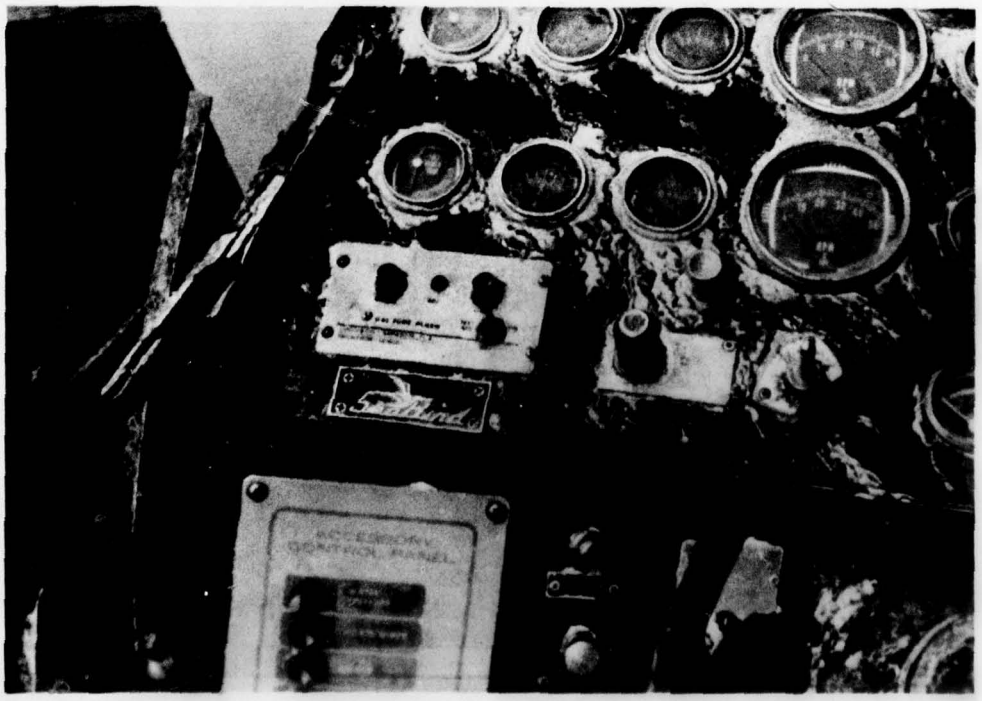


Photograph 34.

APPENDIX H

ACCIDENT INVESTIGATION REPORT

Date of Investigation: July 18, 1976

Date of Accident: Mid-July, 1976

Investigation: Fire/Explosion No. 75-08

SUMMARY — WYLE ACCIDENT NO. 76-312

The accident reported herein involved an 18 ft Larson inboard/outdrive runabout powered by a 155 horsepower Buick engine. The type of accident was an explosion with a subsequent fire, which destroyed the boat beyond reasonable repair. There were no injuries or fatalities resulting from the accident.

At approximately 1630 in mid-July, 1976, two men departed a marina located in North Central Ohio, destined for a fishing location approximately 10 miles out in Lake Erie. The boat had been fueled just prior to leaving the marina.

The men traveled approximately 300 ft to a canal that led to the lake, turned into the canal and headed toward the lake at idle speed. The men smelled something, but thought the odor was coming from a marsh area along the canal. The men could not describe the odor but stated that it did not smell like fuel. After traveling approximately 2000 ft down the canal, the operator noticed that the carpet in front of the engine compartment was wet and the carpet had wrinkled. He suspected the carpet was saturated with fuel because water had never caused the carpet to wrinkle. He started turning the boat around to go back to the marina.

In the turn the men smelled fuel and decided to run the boat aground. Before the boat reached shore, an explosion occurred in the engine compartment with a resulting fire. The men jumped overboard and swam ashore. The boat burned to the waterline before the fire was extinguished by a local fire department.

1.0 BOAT OCCUPANT DATA

Occupants	Sex	Age	Weight	Swimming Ability	Boating Experience	Formal Boating Instructions	PFDs Worn
Operator	M	43	190	Fair	>500 hrs	None	No
Passenger	M	40	175	Fair	>500 hrs	None	No

The operator and passenger had known each other for many years and often fished together in Lake Erie. They seemed to be of normal intelligence and physical ability and possessed at least an average knowledge concerning the safe operation of small boats on large bodies of water. They had owned several outboard and inboard/outdrive boats less than 20 ft in length. According to the passenger, the owner was a fanatic concerning the appearance and proper operating condition of his boat; he cleaned and inspected the boat at least once a week.

2.0 ENVIRONMENT

The sky was clear and the visibility was excellent. The recorded air temperature was 80°F. The wind was from the northeast at 7-14 mph and the water was calm.

3.0 NARRATIVE DESCRIPTION OF ACCIDENT

3.1 Pre-Accident

The owner (1) and passenger (2) were on vacation and had planned a fishing trip for an afternoon in July, 1976. On the day of the accident, the two men worked around their homes during the morning and part of the afternoon. At approximately 1500, (2) arrived at (1)'s house and the two worked on their fishing gear for approximately one hour. During this time, the men stated that they each drank one beer. The men left (1)'s house at approximately 1600, arriving at the marina where the involved boat was kept at approximately 1610.

The men stated that the engine cover was raised to release any fuel vapors, and the engine and associated components were visually checked before the engine was started. Also, they stated that the bilge pump was turned on to make sure that no water was in the bilge prior to starting the trip. The fishing gear and a cooler containing ice and beer was stowed aboard. The engine compartment blower was turned on and the engine started. The boat was then driven at idle speed to a fueling dock approximately 150 ft from the boat slip. The engine and blower were turned off and the boat was fueled. Six gallons of fuel were pumped into the 18 gallon tank, bringing the level to approximately 3/4 full. After fueling, the engine compartment blower was turned on, the engine started, and the men got underway at idle speed toward the lake. The men traveled approximately 300 ft to a narrow canal that led to the lake, then made a 90° right turn into the center of the canal. After traveling approximately 1500 ft, the men smelled an odor similar to the odor that is present in the vicinity of an oil refinery. Both men thought the odor was coming from the marsh area adjacent to the canal. Shortly after detecting the odor, the operator noticed that the carpet in front of the engine compartment was saturated with liquid and was starting to wrinkle. The operator immediately suspected an oil or fuel leak, since the carpet had been saturated with water many times and had never wrinkled. He informed the passenger of his suspicions and told him he was going to turn around and go back to the marina.

3.2 Accident

Gear and people aboard were approximately as shown in Figure 1 and the weather as in section 2.0.

The boat had traveled approximately 2000 ft down the canal and approximately 10 minutes had lapsed from the time the men left the fueling dock.

As the boat turned to port through approximately 120 degrees, the men smelled raw fuel. (1) told (2) he was going to head for shore and beach the boat, because the fuel vapor could ignite. As (1) started to head the boat ashore, an explosion occurred in the engine compartment. (1) was sitting at the helm facing forward and (2) was standing with his left knee on the aft port seat, facing forward. The force of the explosion ripped the engine cover apart and blew it out of the transom area. (1) and (2) were hit in the back and neck by flying debris, probably sections of the engine compartment. After hearing the explosion, (1) turned and looked aft and noticed that the entire engine compartment was on fire and that (2) had not been injured. (1) told (2) to jump overboard because the fuel tank could explode. (1) and (2) jumped over the port side and swam approximately 50 ft to shore. By the time they reached shore (1 minute or less), the entire passenger compartment was on fire.

3.3 Post Accident

The men walked back to the marina and found the marina operator had called the local fire department. The involved boat started drifting back toward the marina. The fire department arrived approximately 20 minutes after the explosion and extinguished the fire. By this time the boat had drifted ashore adjacent to the marina. Refer to Figure 2 and Photograph 1 for the accident area.

TIME SEQUENCE

1500	Passenger arrived at operator's home.
1500-1600	Men prepared fishing equipment.
1600	Left (1)'s home for marina.
1610	Arrived at marina.
1610-1620	Checked boat, loaded gear, went to fueling dock, and pumped six gal. fuel into tank.
1620	Left fueling dock for lake.
1630	Explosion occurred.
1630-1631	Men left boat and swam ashore.
1635	Fire reported to local fire department.
1650	Boat fire extinguished.

4.0 FACTS FROM THE BOAT INSPECTION

The boat was a fiberglass 1969 Larson I/O runabout powered by a 1969 V-6 Buick engine. The outdrive was a 1969 model 155 OMC. The overall length was 18 ft 1 in. Other dimensions could not be determined due to extensive fire damage. The boat was completely gutted by fire, and the only part of the hull remaining was the section that was below the waterline.

According to the operator, the fuel vent was originally located just below the bump rail at the bow. He stated that the vent would occasionally clog up with debris. He had relocated the vent to a position just below the bump rail on the port side approximately 1/3 aft from the bow. This modification had been made for over a year and he stated that the vent had not clogged since. The operator had also installed new carpet approximately one year before the accident.

Refer to Photographs 2-4 for hull damage.

The fuel tank was removed from the boat hull and visually inspected. The tank appeared to be structurally sound and all fittings were secure (all hoses were destroyed). See Photographs 5, 6, and 7.

The fuel line between the fuel pump and carburetor was visually inspected. No breaks or ruptures were found in the line and the end fittings were tight. The output section of the fuel pump, including the threaded output hole, was melted by the fire. See Photographs 8, 9, and 10.

5.0 PSYCHOLOGICAL AND HUMAN FACTORS

It was apparent from the interview that the operator and passenger had considerable experience in operating boats in this class and were aware of the proper safety procedures concerning boat operations. They seemed to be the type individuals that would routinely check their boat and equipment for proper operation prior to setting out on a trip. As far as could be determined, they went through the proper start up safety checks on the day of the accident. The men had never experienced an emergency situation that existed just prior to the explosion. It is believed that when the fuel leak was discovered, the men panicked, which caused their reaction. The operator stated that after the accident he realized that he should have turned off the engine and checked the engine compartment as soon as he suspected the fuel leak.

6.0 PROBABLE CAUSE OF ACCIDENT

The interior of the boat was completely gutted, making it impossible to determine the probable location of the fuel leak. The following theory as to the probable cause is based on what the occupants saw prior to the explosion, and the past experience of the investigator.

The operator noticed that the carpet was saturated in front of the engine cover with a liquid he suspected to be fuel. If it were fuel, this would indicate that the escaping fuel was under pressure and was being sprayed on the forward section of the motor well and was in some way seeping under the carpet. Since the fuel had to be under pressure, the likely location of the leak was in the fuel pump or between the output of the fuel pump and the input of the carburetor. The most likely point was the single diaphragm fuel pump. The pump is at about the level of the sole and would, at idle speed be developing more gasoline pressure and volume than the engine could consume. The fuel vapor in the engine compartment came within the explosive range and was ignited by a spark produced by an electrical component in the engine compartment, since none of the equipment was explosion proofed.

Pressure relief vents would have most likely prevented the destruction of the engine cover which would have restricted the amount of oxygen to sustain the resulting fire. It is likely that pressure relief vents would have prevented the resulting fire or kept it at a low level which could have been extinguished by the on board fire extinguisher.

7.0 DYNAMICS/ANALYSIS OF THE ACCIDENT

The force of the explosion ripped the engine cover apart and blew the pieces out of the transom area, exposing the engine area to the atmosphere which provided oxygen to sustain the fire. Immediately after the explosion, the entire engine area was on fire, which indicates that a considerable amount of raw fuel was in the bilge at this time. Within one minute after the explosion, the entire passenger compartment was on fire, which would support the operator's suspicion that the carpet was saturated with fuel. The fire most likely spread forward on the fuel soaked carpet almost immediately after the explosion, but was not noticed by the occupants due to their mental state at the time and their swift exit from the boat.

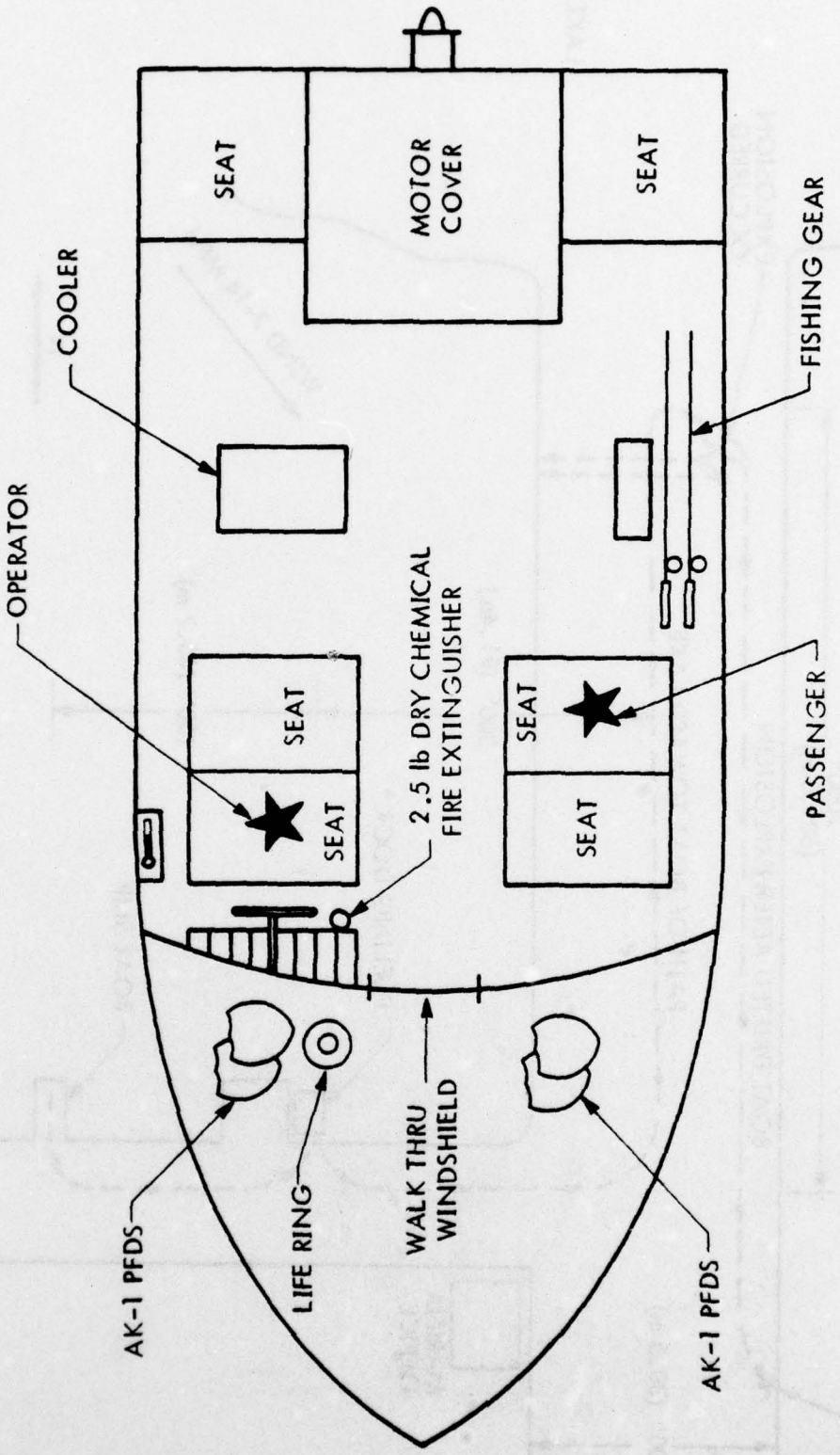


FIGURE 1. LOCATION OF PEOPLE AND GEAR AT TIME OF ACCIDENT

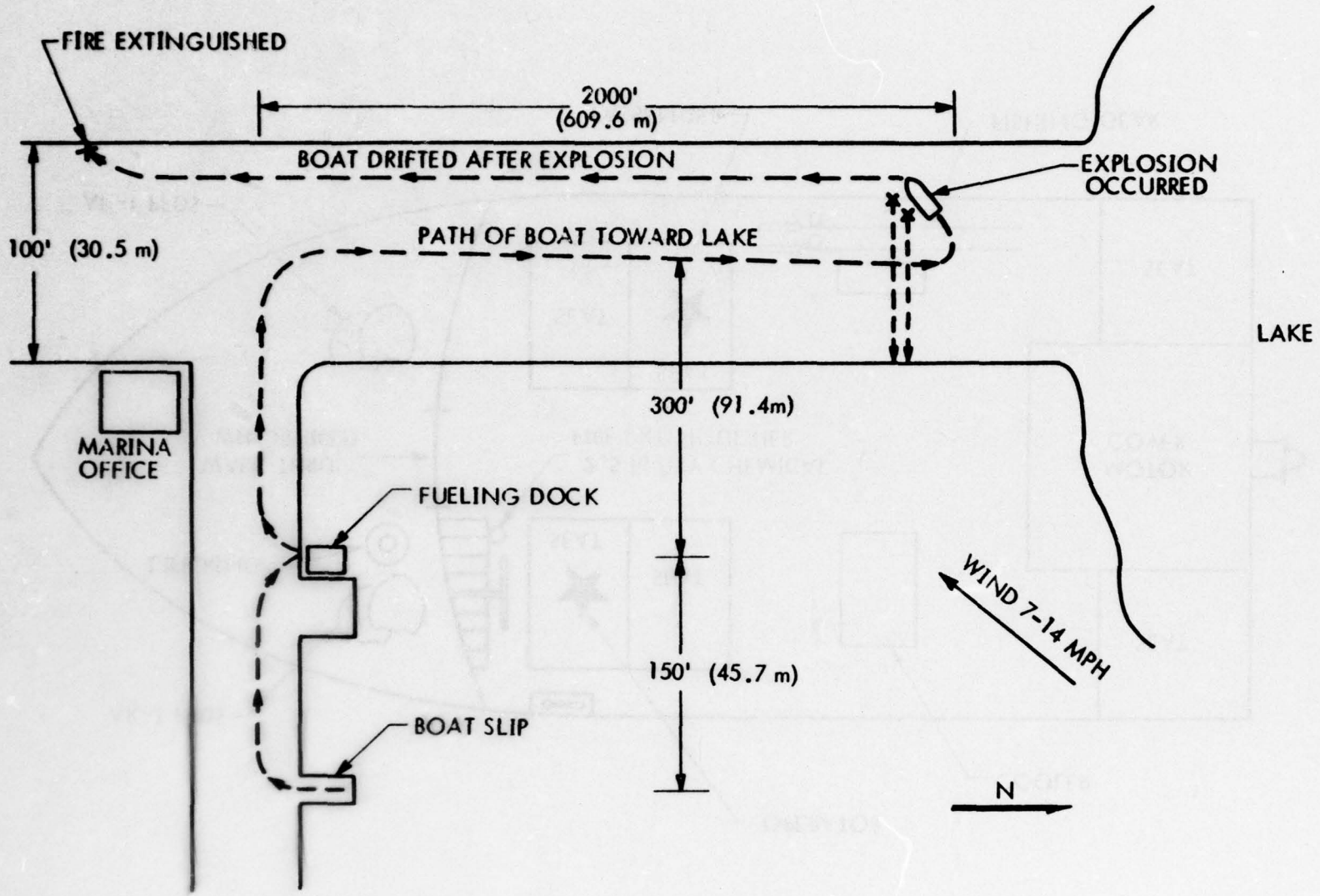
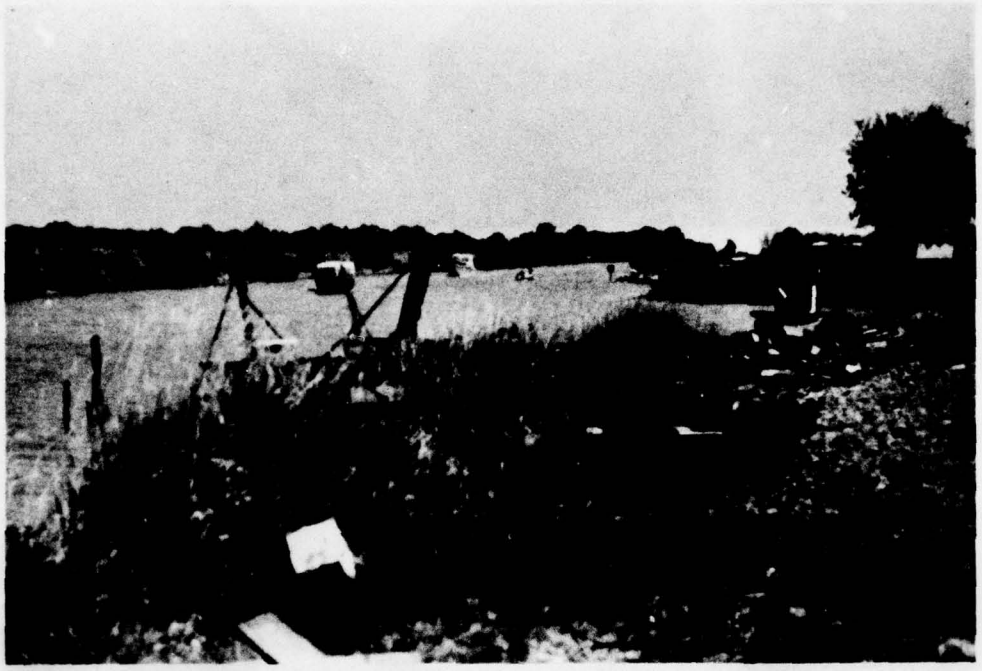
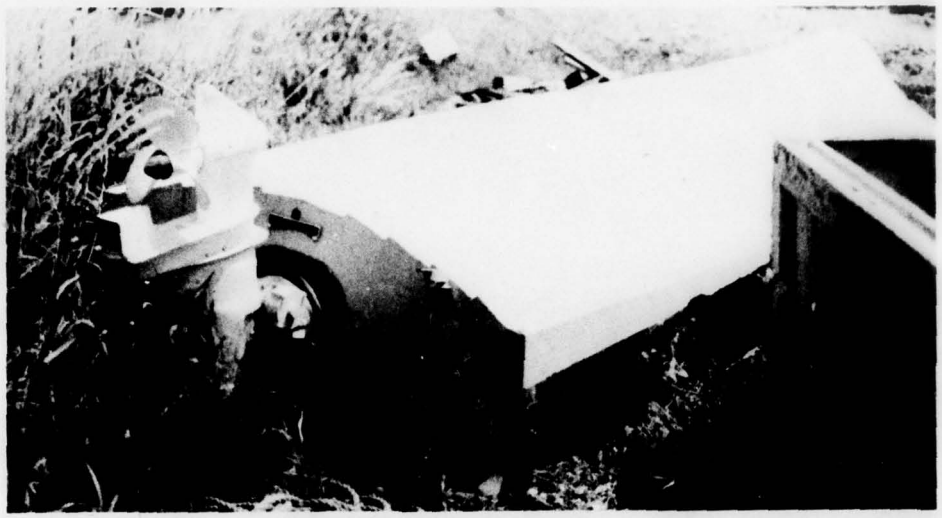


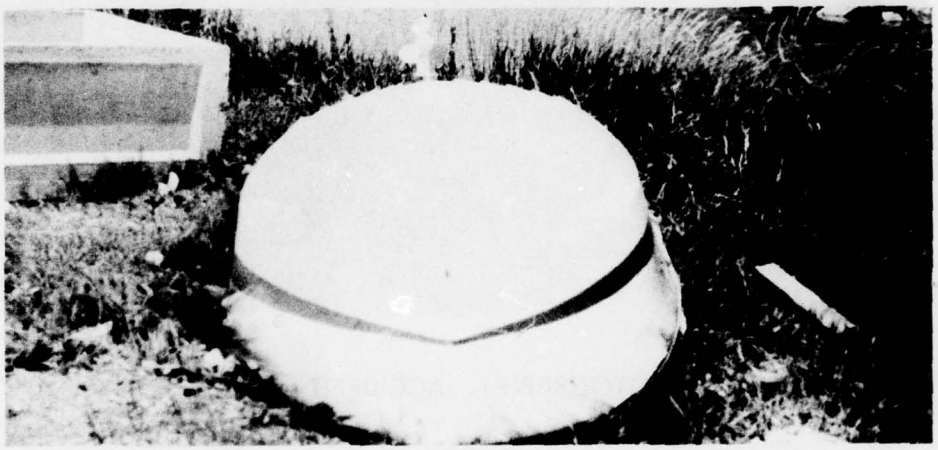
FIGURE 2. ACCIDENT AREA



PHOTOGRAPH 1. ACCIDENT AREA

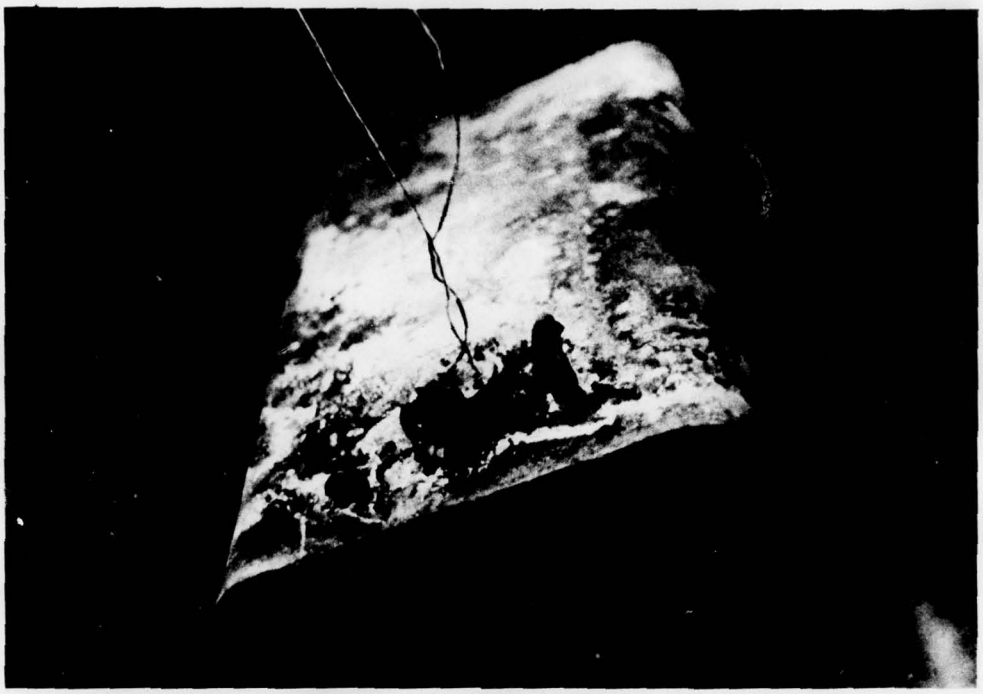


PHOTOGRAPH 2.

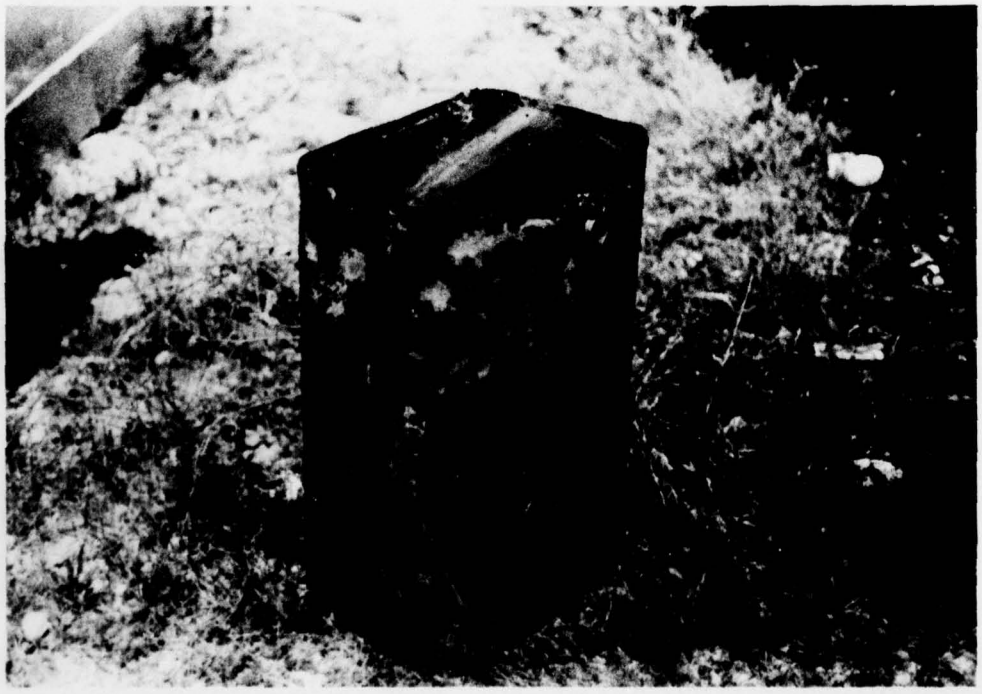


PHOTOGRAPH 3.

PHOTOGRAPH 4.

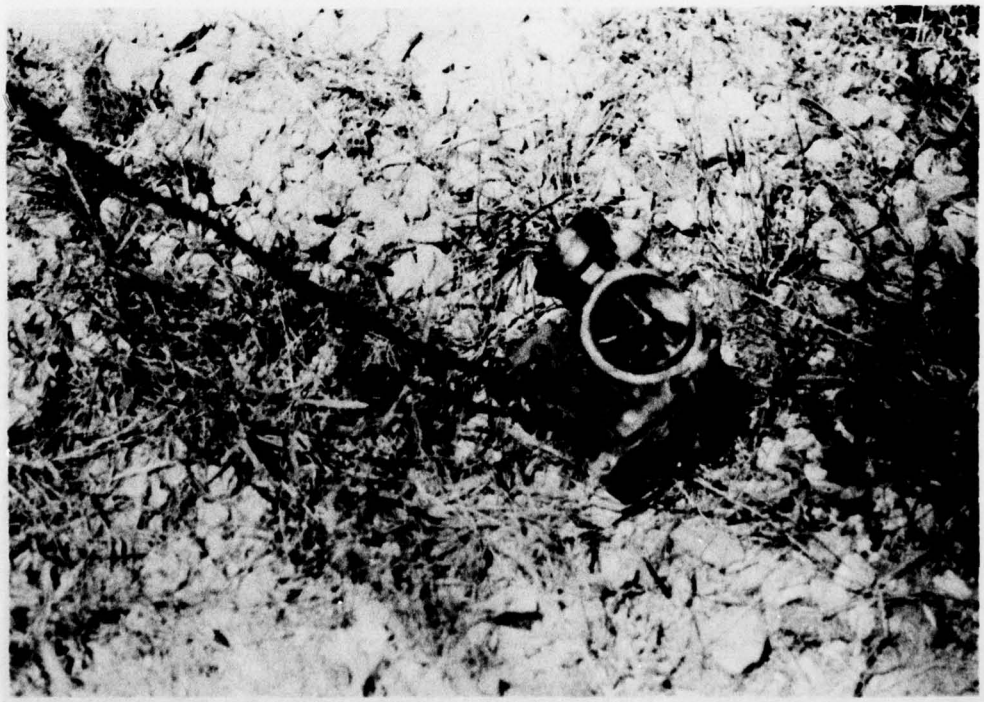


PHOTOGRAPH 5.



PHOTOGRAPH 6.

PHOTOGRAPH 7.



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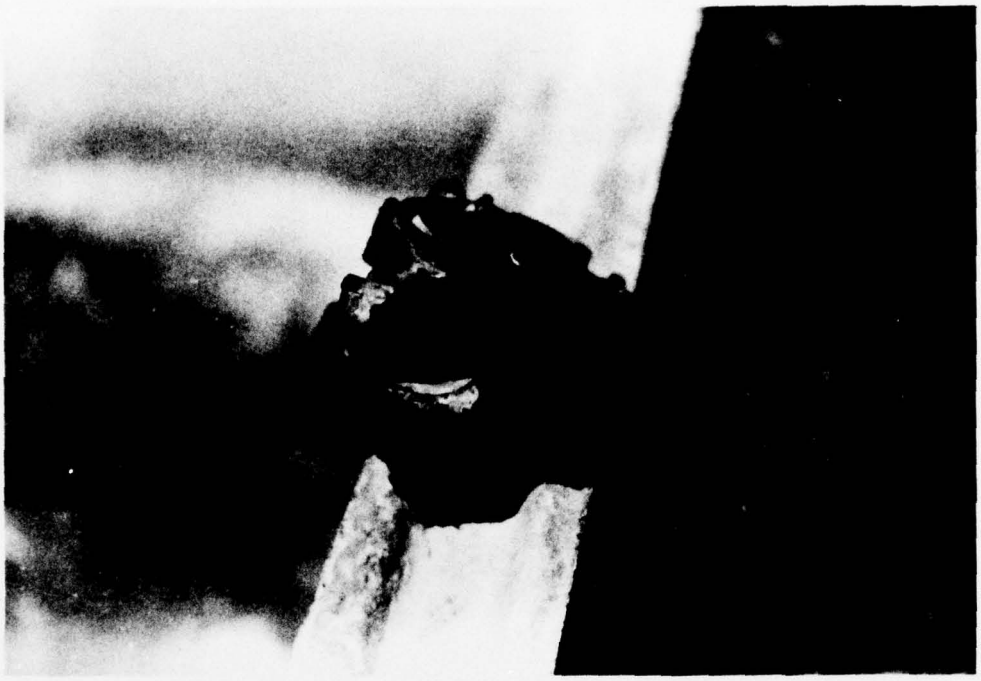

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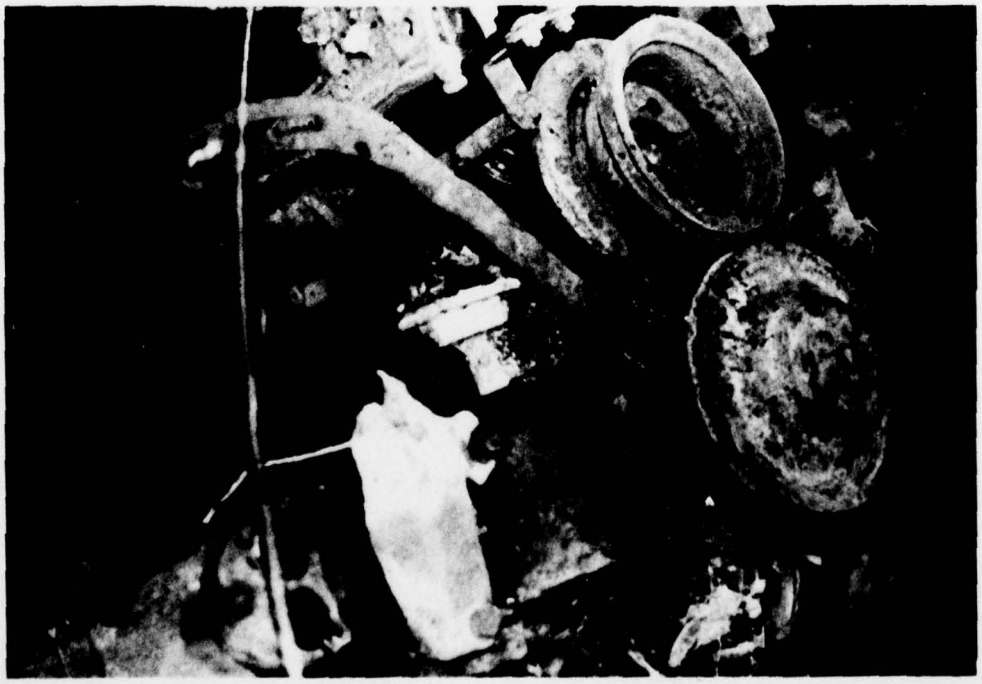

PHOTOGRAPH 10.

APPENDIX I

ACCIDENT INVESTIGATION REPORT

Date of Investigation: July 20, 1976

Date of Accident: Mid-July, 1976

Investigation: Fire/Explosion No. 75-09

SUMMARY — WYLE ACCIDENT NO. 76-347

The accident reported herein involved a 22 ft I/O cabin cruiser powered by two 130 horsepower engines. The type of accident was an explosion with a subsequent fire, which destroyed the boat beyond repair. The market value of the boat was estimated to be between 10 and 12 thousand dollars. There were no injuries sustained by any of the four occupants aboard.

At approximately 0500 in mid-July, 1976, a fishing party consisting of three adult males and one female child got underway from a private dock located in east central South Carolina destined for a fishing area 30 to 50 miles off the east coast. The operator noticed when they left the dock that the engines were not running properly. After being underway for approximately three minutes, a passenger observed that black smoke was coming from the exhaust; shortly thereafter, the starboard engine stopped. The operator restarted the engine and asked one of the passengers to raise the motor cover and see if he could see anything that would cause the engines to run rough. The passenger raised the cover, and immediately the engines began to run normally. It was too dark for the passenger to see the engine clearly, so he lowered the cover and asked another passenger to get a flashlight. As the passenger started forward to get the flashlight, an explosion occurred in the engine compartment. The occupants

saw flames coming out of the transom hatch cover and decided to jump overboard. Before jumping overboard, the operator grabbed four AK-1 PFDs. The occupants held to the PFDs and swam approximately 1/8 mile to shore. The boat drifted to a sandbar and burned to the waterline.

1.0 BOAT OCCUPANT DATA

Occupants	Sex	Age	Weight	Swimming Ability	Boating Experience	Formal Boating Instruction	PFDs Worn/Used
(1) Operator	M	41	200	Good	>500 hrs	None	Yes
(2) Passenger	M	38	180	Good	>500 hrs	None	Yes
(3) Passenger	M	42	200	Good	>500 hrs	None	Yes
(4) Passenger	F	11	50	Good	50-100 hrs	None	Yes

1.1 Operator/Owner (1)

The operator was a college graduate and was self-employed as a landscape architect. From the interview it was apparent that he possessed at least an average knowledge concerning boat operating and safety procedures to be used while operating the type boat involved in the accident. He had operated and crewed on boats ranging from small johnboats to sea-going vessels. He stated that he had over 500 hrs operating experience in the type and size of the involved boat. He stated that he inspected the boat and ran it on short cruises almost daily to insure that it was always in top, seaworthy condition.

1.2 Passenger (2)

He was a college graduate and was self-employed as an architect. His boating experience was similar to the operator's, and he was equally knowledgeable concerning safe boating operating procedures. He had known the operator for a number of years and had been on fishing trips with him almost weekly for the past two years.

1.3 Passenger (3)

He was not available for interview at the time of the investigation. According to the operator, his boating experience was about the same as his own. He also had known the operator for a number of years and usually went on the weekend fishing trips.

1.4 Passenger (4)

She was the daughter of the operator and had missed very few of the weekend fishing trips over the past two years. It was apparent from the interview that she was much more knowledgeable concerning safe boating operating procedures than most people her age. Over the past year, the operator had taught her to operate the boat and basic navigation.

2.0 ENVIRONMENT

The sky was clear and the visibility was restricted only by darkness. The recorded air temperature was 74°F and the water temperature was 74°F. The water was calm and the wind was from the northwest at 0-6 mph.

3.0 NARRATIVE DESCRIPTION OF ACCIDENT

3.1 Pre-Accident

At approximately 1700 on the day before the accident, the operator fueled the involved boat at his private dock, bringing the fuel level up to approximately 70 gallons. According to the operator, he raised the engine cover and visually inspected the engines and associated components. He then took the boat out and ran it up and down the river for approximately 15 minutes. He stated that the engines ran normally, and he detected no gasoline fumes during or after the short cruise.

On the day of the accident, the operator (1) and his daughter (4) arose at approximately 0330 and started preparing for the fishing trip. They ate breakfast and went down to the dock (located at the owner's residence) to prepare the boat for the trip. (4) boarded the boat, went forward to the cabin, and lay down on the starboard bunk. (1) topped the fuel tank, bringing the fuel level up to where the gasoline was visible in the fill hose. He stated that there was no overflow from the filler fitting during the fueling operation. He filled a five gallon plastic container with fuel and placed it aft of the rear facing starboard seat. Normal practice in the past had been to put the five gallons of fuel in the boat tank when they reached the ocean to insure that enough fuel was aboard to make the trip out and back. (1) decided to start the engines and check their operation before the other two passengers arrived. He turned on the engine compartment blowers, but did not remember if he raised the engine cover prior to starting the engines. The engines were started and, according to the owner, ran normally. The engines were stopped after a few minutes, and (1) and (4) waited for the other two passengers to arrive. At approximately 0430, (3) arrived and loaded his gear aboard. The party had planned to get underway at 0430, but (2) had overslept and did not arrive until approximately 0500. He loaded his gear aboard, including a cooler full of ice. (1) turned on the engine compartment blower and started the engines. The party got underway shortly after 0500. When the boat cleared the dock area, (1) applied power to get the boat on plane. He noticed that the engines were not running smoothly and were not developing sufficient power to get the boat on plane. (3) was lying across the engine cover with his head resting on a life cushion. He shouted to the operator that something was stinking, and he could see black smoke coming from

the exhaust. At this point (1) detected the odor which smelled like the odor which is emitted by an oil refinery. He thought the odor was coming from something on shore and that the engines were a little flooded and would be all right. As a precaution, he turned on the engine compartment blower to evacuate any fuel vapors that could be in the engine compartment. Shortly after the blower was turned on, the starboard engine stopped. (1) restarted the engine with no difficulty. (1) then instructed (3) to raise the engine cover for a visual check because the engines were still running rough. (3) got off of the engine cover and raised it, but it was not light enough to see the engines clearly. When the cover was raised, the engines started running normally.

3.2 Accident

Gear and people aboard were approximately as shown in Figure 1, and the weather as in section 2.0.

(3) lowered the engine cover and asked (2), who was arranging food and drinks in the cooler located on the starboard side, to get a flashlight from a port side storage cabinet. (2) immediately started forward to get the flashlight. When he reached a position in the center of the boat and adjacent to (1), an explosion occurred in the engine compartment. Approximately 10 seconds had lapsed from the time (3) had lowered the engine cover and the boat had been underway for approximately three minutes. (1) and (2) looked aft and noticed that blue flames approximately two ft high were coming from the starboard access opening, and the clothing on (3)'s back was on fire. (2) started looking for something to smother the burning clothing on (3), but noticed that the flames on the clothing went out in a few seconds. (1) told (2) and (3) to jump overboard because the fuel tank could explode. (1) went into the cabin to get (4), and when he turned to bring her out, he noticed that (2) was still aboard. He pitched (4) into the arms of (2) and grabbed four AK-1 PFDs that were in the cabin. (3) had immediately jumped over the starboard side when instructed to do so by (1). (2) had hesitated, considering whether he should try to put the fire out with the fire extinguisher. He could see flames around the starboard engine through the engine cover air scoop and decided not to attempt to extinguish the fire. (2) carried (4) to the starboard side and threw her overboard. (4) had managed to grab the life cushion that had been on the engine cover before she was thrown

overboard. (1) exited the cabin, threw the PFD over the starboard side, and immediately jumped overboard at the starboard stern.

3.3 Post Accident

Each occupant grabbed an AK-1 PFD. (1) swam a few yds to (4) and held her up while she put on an AK-1 with apparently no difficulty.

Within the first two minutes after the explosion, the fire in the engine compartment did not seem to increase in intensity or spread. (1) decided that the fire was small enough to be extinguished by the fire extinguisher on board. He told (2) and (3) he was going back aboard and try to put out the fire. (2) and (3) convinced him that it would be foolish to go back aboard because the fuel tank could explode. The occupants decided to swim ashore (approximately 1/8 mile) and get help to put out the fire. It took approximately 15 minutes for the party to reach shore. Within five minutes after the explosion, the flames had spread to the helm and the flame color had changed from blue to red and was much more intense. By the time the occupants reached shore, the entire boat was ablaze, and it was evident that nothing could be saved. The boat burned to the water line and drifted ashore on a sandbar. Refer to Figure 2 for sketch of accident area.

4.0 FACTS FROM THE BOAT INSPECTION

At the time of the investigation, the boat had not been recovered. The following information was obtained from the owner.

The boat was a 22 ft 1962 model Scotty Craft I/O cabin cruiser powered by two 1974 model 130 horsepower Volvo engines. The hull was a deep-V design of fiberglass construction. The engines had been installed (new) by the owner two years prior to the accident. The owner estimated that the engines had been run approximately 170 hours. The owner had also had a fiberglass fuel tank fabricated to replace the metal tank that had developed a leak. He installed the fiberglass tank in a wooden framework which allowed for four inch foam to be placed around the sides, top, and bottom. The fiberglass tank had been installed prior to installing the new engines. The aft end of the tank was located approximately two ft from the engines. No fuel vapor detector was installed on the boat. Refer to Figure 1 for boat layout.

5.0 PSYCHOLOGICAL AND HUMAN FACTORS

The three adults aboard the involved boat were well educated with at least an average knowledge concerning operation of boats in this class. As far as could be determined, proper safety procedures concerning startup and underway operations were normally followed. Each man had over 500 hrs operating experience in the type boat involved in the accident and had never experienced an on board fire. Also, they had been on fishing trips with each other almost weekly for the past three years. Since they had never experienced an on board fire, considering their experience, they were likely somewhat complacent regarding the possibility of having a fire-related accident.

The operator stated that he raised the engine cover and visually inspected the engine compartment for fuel and water leaks on the day before the accident. He stated that he did not remember if he raised the cover and checked the engines on the day of the accident. The passengers did not see him raise the cover, and since he had checked the engines and bilge the day before, he most likely did not perform a visual inspection on the day of the accident. During the interview, (2) stated that (1) maintained his boat well and usually operated his boat in a responsible manner. However, (2) stated that on occasion (1) would operate his boat in a manner that was contrary to standard safety procedures, such as, not raising the engine cover to check for fuel vapor and starting the engines immediately after turning on the blower.

6.0 PROBABLE CAUSE OF ACCIDENT

The operator and passengers stated that the engines started to run rough shortly after getting underway, and black smoke was seen coming from the exhaust. Considering the black smoke being emitted from the exhaust, it is assumed that the fuel air mixture ratio was improper, most likely caused by fuel vapors in the engine compartment being ingested into the carburetor intakes which increased the fuel to air ratio. At this point, the engines were not hot and the temperature in the engine compartment could not have been high enough to vaporize raw fuel in the bilge if a leak in the fuel system had caused raw fuel to accumulate in the bilge. Therefore, it is likely that the fuel leak was on the output side of the fuel pump, which caused the fuel to be discharged under pressure as a mist rather than a solid stream. Complete fuel vaporization probably occurred by fuel droplets contacting warm engine components. Since the explosion did not occur until the engine cover was raised, the fuel mixture in the engine compartment probably increased rapidly to a level outside the explosive range (higher than the upper explosive limit). When (3) raised the engine cover, sufficient oxygen entered the engine compartment to rapidly lower the fuel vapor mixture to a level outside the explosive range (lower than the lower explosive limit). When the cover was lowered, the fuel vapor mixture immediately started to increase as the oxygen level decreased. The explosion occurred when the lower explosive limit was reached, as was evident from the flame color (blue) seen by the occupants.

The engine cover was not detached from the boat by the explosion, which would indicate that the explosion was of low intensity. Had the boat been equipped with pressure relief vents, the resulting fire would have most likely been very small or would have gone out due to lack of oxygen. Since the boat was completely destroyed, the probable source of ignition could not be determined.

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7.0 DYNAMICS/ANALYSIS OF THE ACCIDENT

The force of the explosion raised the front end of the hinged engine cover (cover hinged at stern end) and blew off the starboard stern access cover. The overpressure in the engine compartment was relieved by the open engine cover and access cover. After the explosion, the engine cover fell back down into its normally closed position which essentially sealed the engine compartment. The access cover was hinged at the transom end and had no mechanism to sustain its flopping motion. The cover swung to the fully open position and ripped the aft hinges loose from the boat structure, allowing the cover to become detached from the boat. This opening provided sufficient oxygen to sustain the fire resulting from the explosion. The presence of flames after the explosion indicates that raw fuel was in the bilge. The fuel fire eventually ignited the wood and fiberglass material in the engine compartment and spread until the entire boat was on fire. The boat burned to the water line and was deemed a total loss.

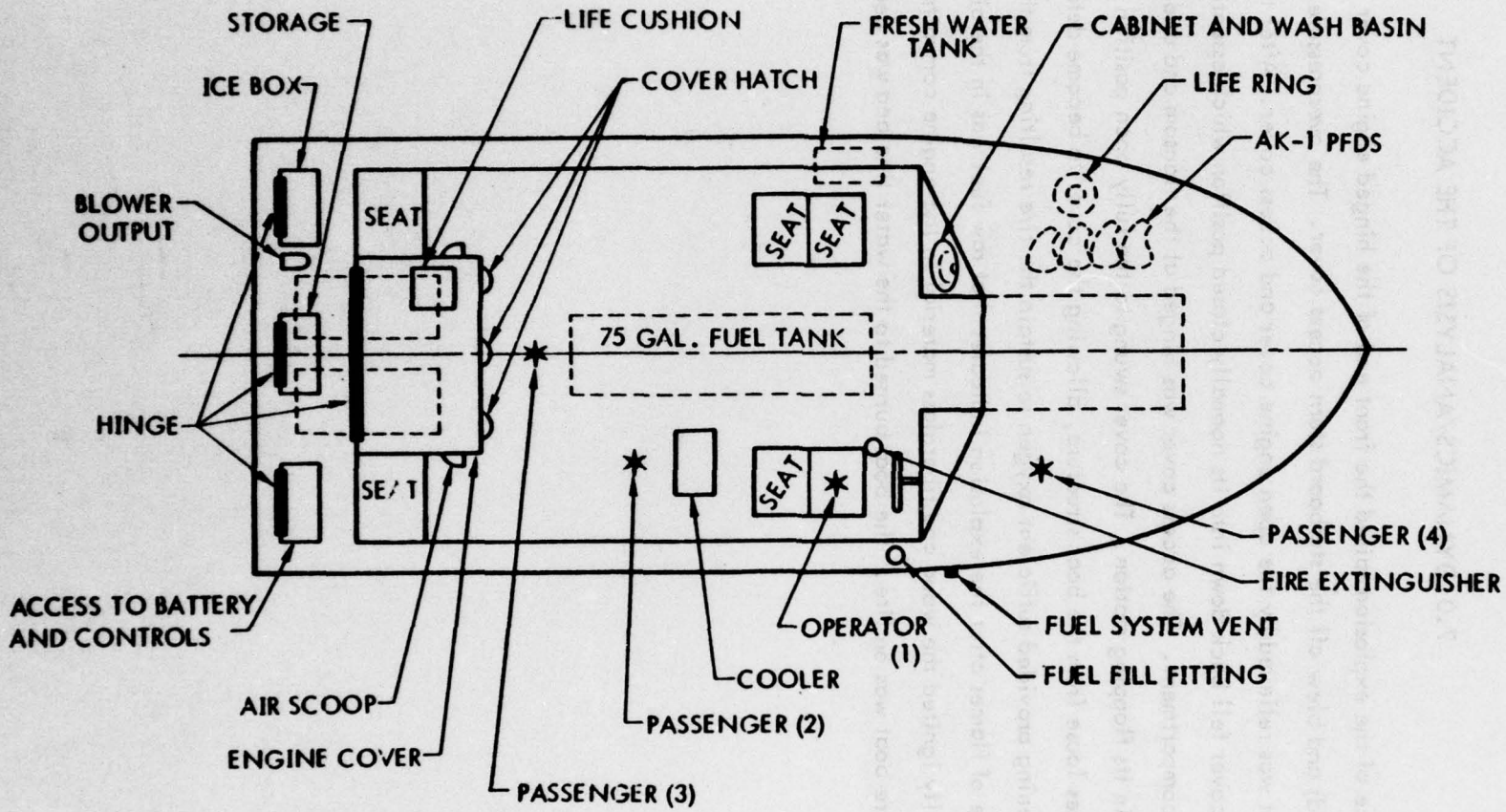


FIGURE 1. LOCATION OF PEOPLE AND GEAR AT TIME OF ACCIDENT

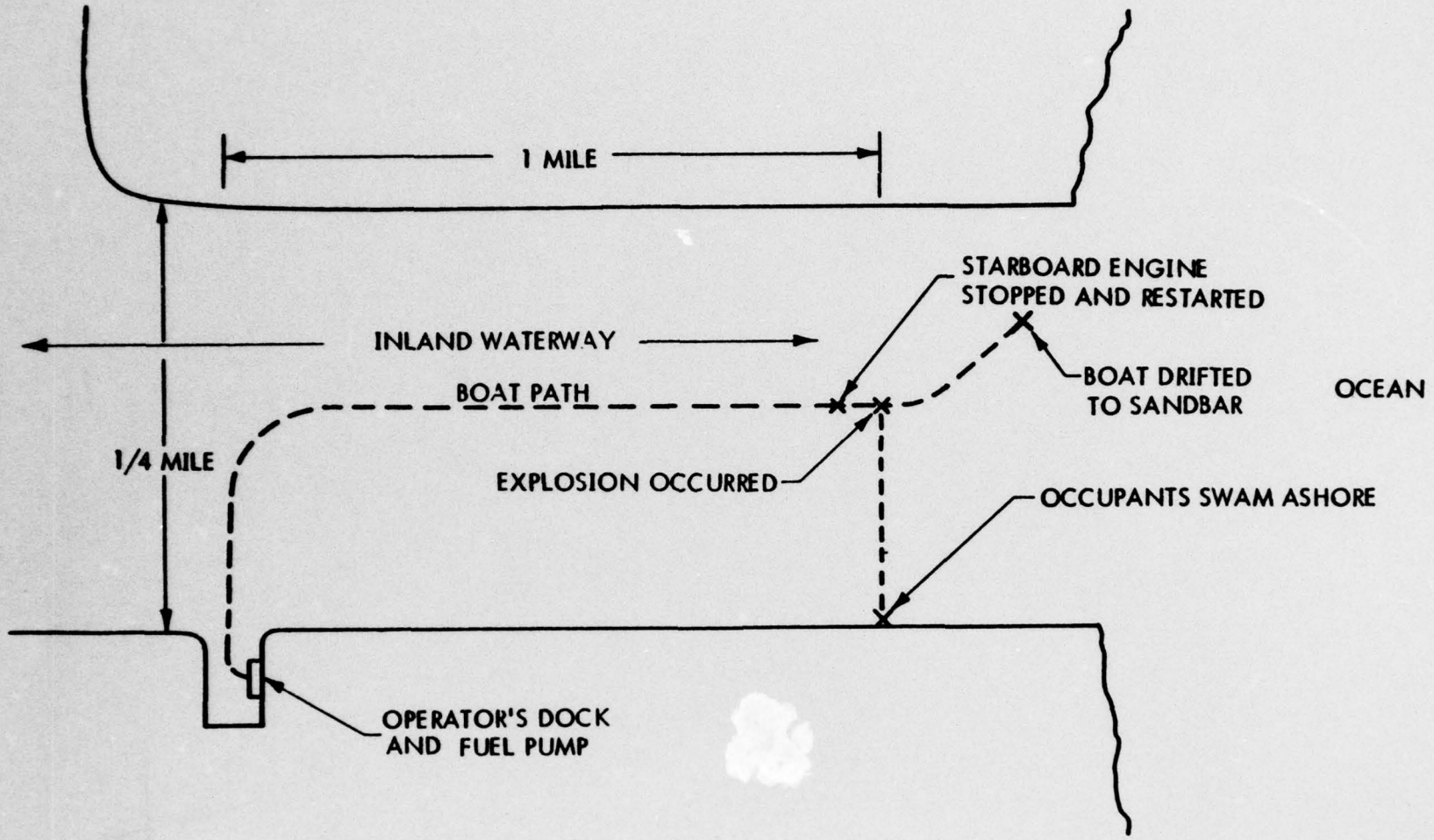


FIGURE 2. ACCIDENT AREA

APPENDIX J

ACCIDENT INVESTIGATION REPORT

Date of Investigation: August 7, 1976

Date of Accident: May 16, 1976

Investigation: Fire/Explosion No. 75-10

SUMMARY — WYLE ACCIDENT NO. 76-117

The accident reported herein involved a 20 ft (6.1 m) inboard/outdrive (jet outdrive) cabin cruiser powered by a 205 horsepower engine. The type of accident was an explosion with a subsequent fire, which destroyed the boat beyond reasonable repair. The estimated value of the boat was $6,000. There were no fatalities or injuries resulting from the accident.

At approximately 0930 on May 16, 1976, two men arrived at a marina located in Port O'Conner, Texas after a fishing trip in the Gulf of Mexico. The men had traveled at top speed [approximately 25 mph (40.2 kph)] from the fishing area located approximately 12 miles (19.3 km) off shore. When they reached the launch area at the marina, several boats were waiting to be hoisted out of the water. The men cruised around in the area near the boat hoist at 4-5 mph (6.4 - 8 kph) for a period of approximately five minutes. The boat was cruising parallel to the shore at a distance of approximately 50 ft (15.2 m) when a low level explosion occurred in the engine compartment. Shortly after the explosion, the operator and passenger saw flames coming from under the front and sides of the engine cover. The men did not attempt to extinguish the fire, because they were afraid the fuel tanks installed on either side of the engine would explode. The men exited the boat through the cabin forward window and boarded a cabin

cruiser that had witnessed the accident and had maneuvered to the bow of the burning boat. The boat drifted ashore and the fire was extinguished within 15 minutes after the explosion occurred.

1.0 BOAT OCCUPANT DATA

Occupant	Sex	Age	Weight	Swimming Ability	Boating Experience	Formal Boating Instructions	PFDs Worn Before	PFDs Worn After
Operator	M	60	175 (79 kg)	Good	>500 hr	C.G. Aux.	No	No
Passenger	M	58	175 (79 kg)	Good	>500 hr	None	No	No

The owner/operator was the only occupant available for interview at the time of the investigation He worked as an Industrial Instrumentation Designer and seemed to be of average intelligence and physical ability. He had completed a power squadron boating safety course and seemed to possess at least an average knowledge of the proper operating and safety procedures for the size of the involved boat. He and the passenger had fished in the accident area numerous times and had never experienced an on board fire or any other type accident. He seemed to be the type individual that would be very conscientious concerning the condition and safety of his boat.

According to the owner, the passenger was of normal intelligence and physical ability and had approximately the same background and experience as his own.

2.0 ENVIRONMENT

The sky was clear and the visibility was good. The wind was from the south at 0-6 mph (0-9.7 kph), and the water was calm. The recorded air temperature was 74°F (23°C), and the recorded water temperature was 76°F (24°C).

3.0 NARRATIVE DESCRIPTION OF ACCIDENT

3.1 Pre-Accident

On the day before the accident, May 15, 1976, the operator (1) and a friend (passenger 2) trailered the involved boat from (1)'s home to a marina located at Port O'Conner, Texas, approximately 70 miles (112.7 km) away. They arrived at the marina at 1200 and launched the boat. (1) stated that he raised the engine cover, inspected the engine and bilge, and topped off the two 22 gal. (83.3 l) fuel tanks. He also filled a five gal. (18.9 l) fuel can that was in the aft section of the boat. During the afternoon, the men fished in the bay two to three miles (3.2-4.8 km) from the marina. They spent the night on the boat anchored near a jetty.

The next morning the men arose at 0600 and shortly thereafter got underway to a fishing area located approximately 12 miles (19.3 km) off shore in the Gulf of Mexico. The operator stated that he inspected the engine and bilge prior to starting the engine. No evidence of fuel leaks were observed. During the visual inspection, (1) discovered a loose generator belt which he tightened. They arrived at the fishing area at 0700 and trolled at slow speed [3-4 mph (4.8-6.4 kph)] until approximately 0900. Fishing was not good, and the men decided to return to the marina. The fishing gear was stowed, and they got underway at full speed [approximately 25 mph (40.2 kph)] arriving at the marina at approximately 0930. When they approached the launch area, they noticed that two or three cabin cruisers were waiting to be hoisted out of the water. (1) slowed the boat to idle speed and started maneuvering around in the area of the hoist, awaiting his turn to use the hoist.

3.2 Accident

Gear and people aboard were approximately as shown in Figure 1, and the weather as noted in Section 2.0.

After cruising around for approximately five minutes, the boat was cruising parallel to the shore at a distance of approximately 50 ft (15.2 m). At this point, a low level explosion occurred in the engine compartment. (1) was standing at the helm facing forward and (2) was

standing, leaning against the front of the engine cover, facing forward. After the explosion, (1) looked aft and saw that the back of (2)'s shirt was on fire. Before (1) could move aft, the fire on (2) went out. At this point, (1) stated that no flames were visible in the stern section. The force of the explosion had raised the engine cover which was hinged from the transom, but it apparently had quickly flapped shut. Within seconds (1) noticed that flames began coming from under the front and sides of the engine cover. (1) and (2) were now positioned amidships. (2) told (1) to go through the cabin, climb out the forward window and get out of the boat because the fuel tanks could explode. (1) considered fighting the fire with a 2-1/2 lb (1.1 kg) dry chemical extinguisher aboard, but quickly decided he should do what (2) suggested and get out of the boat.

3.3 Post Accident

(1) went through the cabin and climbed through the forward cabin window onto the bow with (2) following. The crew of a nearby cabin cruiser had witnessed the explosion and had maneuvered their boat to the bow of the involved boat which (1) and (2) boarded. Shortly after (1) and (2) boarded the cabin cruiser, a second explosion occurred (high level) in the engine compartment. The force of this explosion ripped the engine cover apart and blew the pieces out of the stern area, exposing the engine compartment to the atmosphere. The height of the flames rapidly increased to 10-12 ft (3-3.7 m). Shortly after the second explosion, a small commercial fishing boat pulled alongside the involved boat, and one of the occupants aboard started discharging a medium size dry chemical fire extinguisher into the stern section of the burning boat. The operator shouted to the crew of the commercial boat to get away from the burning boat because the fuel tanks could explode. The commercial boat pulled away and the involved boat drifted to shore. By the time the boat reached shore, the entire interior was on fire.

Approximately 20 minutes after the explosion, the local fire department arrived and extinguished the major part of the fire. The starboard side could not be extinguished because it was facing seaward and could not be reached by the land vehicle equipment. A Coast Guard vessel arrived on the scene approximately 25 minutes after the explosion and extinguished the fire on the starboard side. Refer to Figures 2 and 3 for the accident area.

3.4 Time Sequence

0600	Arose and made preparations to get underway to the fishing area.
0700	Arrived at fishing area 12 miles (19.3 km) off shore.
0700-0900	Troll fished at idle speed.
0900	Departed fishing area for marina.
0930	Arrived at marina.
0930-0935	Cruised around launch area at idle speed.
0935	Explosion occurred in engine compartment.
0935-0936	Occupants left involved boat and boarded cabin cruiser.
0936	Second explosion occurred in engine compartment.
0936-0937	Commercial boat tried to extinguish fire.
0937-1000	Boat drifted ashore and fire spread over interior of boat.
1000	Fire department arrived and extinguished majority of fire.
1005	C. G. vessel arrived and extinguished remaining fire.

4.0 VESSEL DATA

The boat was a semi-V fiberglass 1959 model Vancraft cabin cruiser powered by a 205 hp 1965 Buick engine. The outdrive was a water jet manufactured by Rev-Jet in 1965. According to the operator, he installed the engine and outdrive new in 1965. A 22 gal. (83.3 l) fiberglass fuel tank had been built into the hull on each side of the engine compartment. As shown in Figures 4-10, the interior of the boat was completely gutted by the fire. The only components of the fuel system that could be visually inspected for a possible source of fuel leakage were the fuel tanks. The other components comprising the fuel system were so badly deteriorated that evidence of a fuel leak would have been destroyed. No ruptures or likely fuel leak areas could be found on the fuel tanks. Both tanks were fiberglass.

This was the first time the boat had been out during 1976. The operator stated that during the six months preceding the accident, he had installed all new flex fuel lines and visually examined all rigid lines. He had operated the engine for approximately one hour at his home, two days before the accident.

He stated that the engine ran perfectly and there were no leaks in the fuel system.

5.0 PSYCHOLOGICAL AND HUMAN FACTORS

The occupants of the involved boat were experienced boat operators, particularly in the type and size of the involved boat. The operator seemed to be very conscientious concerning the condition and safety of his boat and, as far as could be determined, always went through the proper safety checks prior to operating his boat. He stated that the boat was old, and he felt it required constant care to insure that it remained in a safe and seaworthy condition.

The operator and passenger had never experienced an on board fire and were not sure of what would happen after the explosion. The operator stated that had he known the fuel tanks were unlikely to explode, he could have probably extinguished the fire with the dry chemical fire extinguisher.

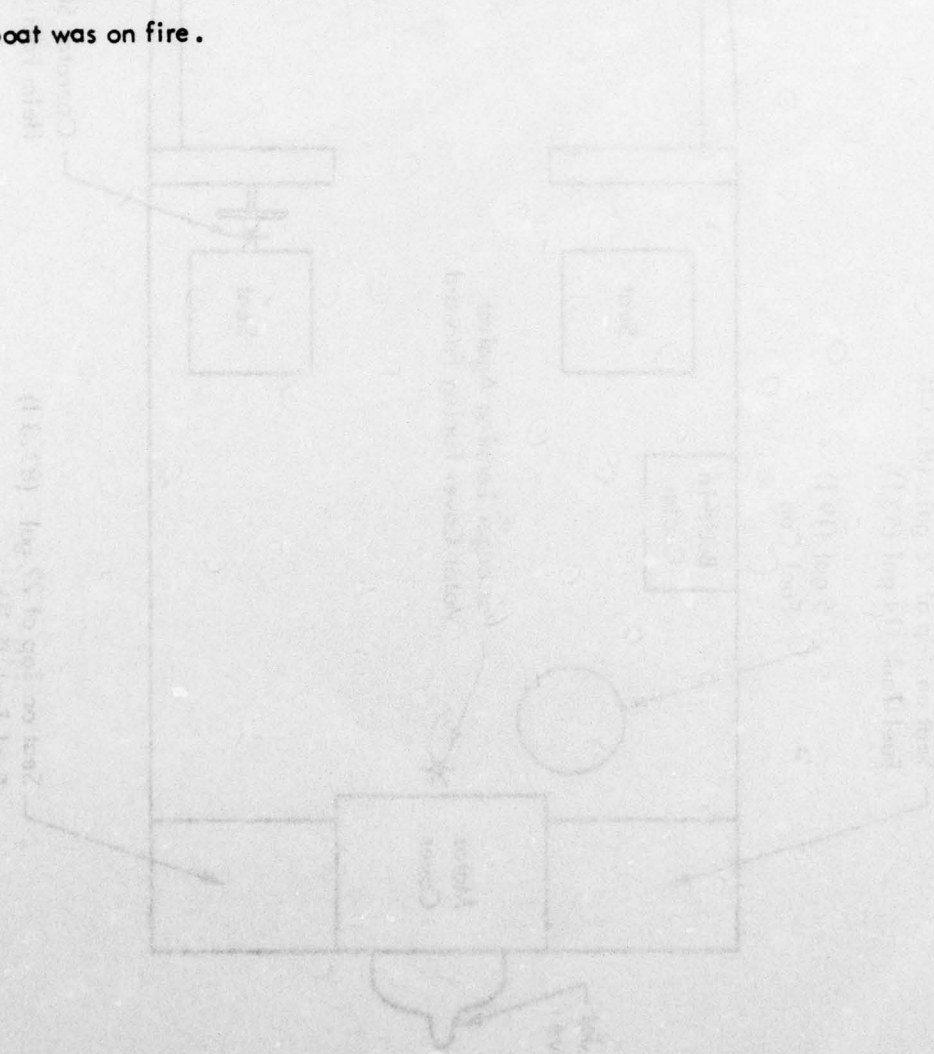
6.0 PROBABLE CAUSE OF ACCIDENT

As shown in the Figures 4-10, the interior of the boat was completely gutted and the probable source of fuel leak causing the explosion could not be determined. The fuel tanks appeared to be structurally sound and, according to the operator, the fuel lines and fittings were in good condition. The fuel pump and carburetor were old and are considered to be the likely source of fuel leakage. Due to the age of the boat and motor, none of the electrical components were explosion proof, and any one of these units could have been the source of ignition.

Properly installed pressure relief vents could have possibly prevented the fire after the initial explosion, providing the engine cover was properly sealed and secured. Relief vents would have most likely prevented the destruction of the motor cover during the second explosion, which would have restricted the oxygen supply to the engine compartment fire.

7.0 DYNAMICS/ANALYSIS OF THE ACCIDENT

The initial explosion was low level, and the fire was contained under the engine cover. Openings to the engine compartment allowed oxygen to enter and sustained the fire. The fire increased in intensity until flames were coming from under the front and sides of the engine cover. The second explosion destroyed the engine cover which exposed the fire to the atmosphere. Immediately after the second explosion, the fire intensified rapidly, which indicates that a considerable amount of raw fuel was in the bilge. The wood and fiberglass material around the engine compartment was ignited by the fuel fire and spread forward until the entire interior of the boat was on fire.



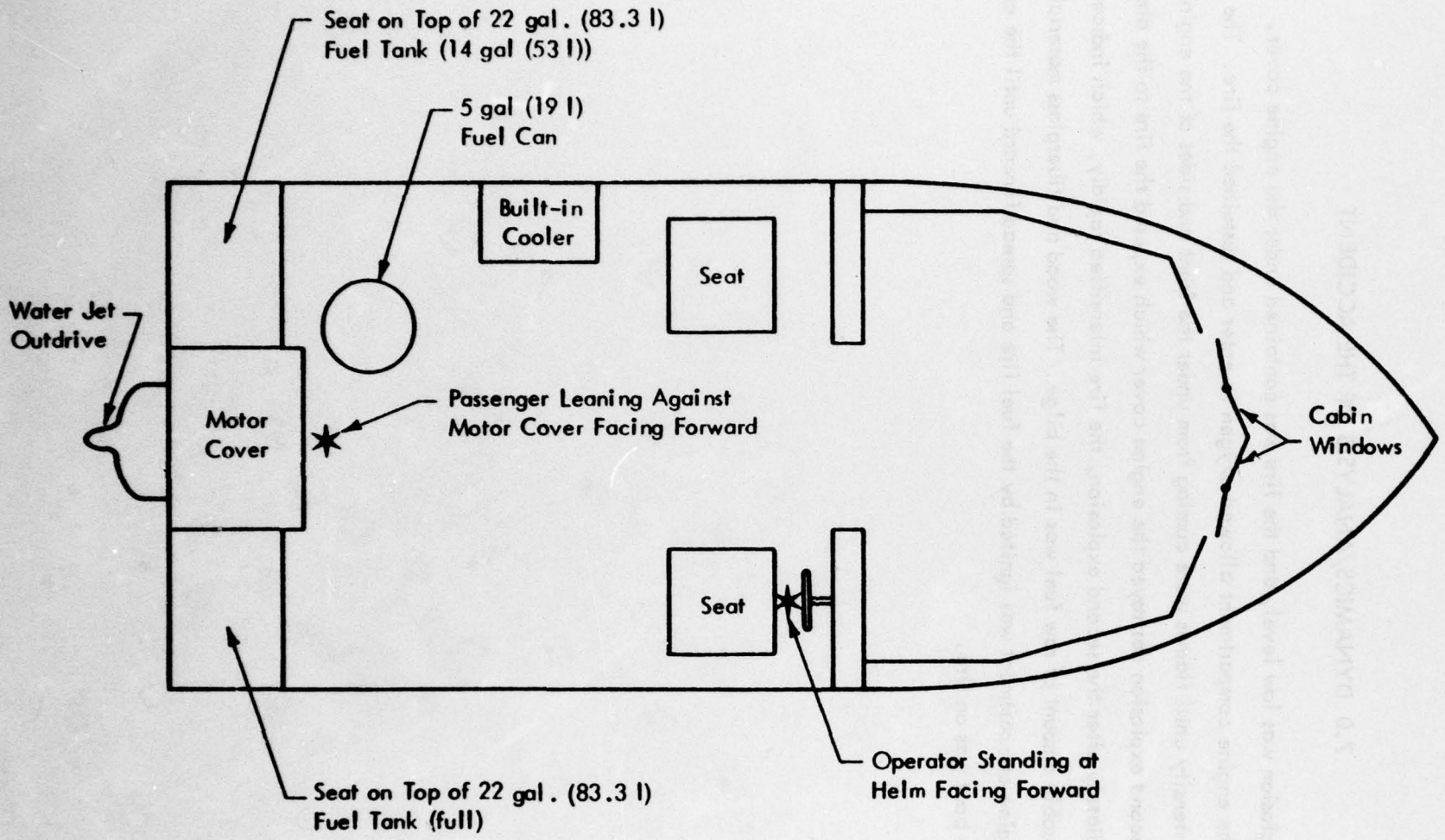


FIGURE 1. OCCUPANTS AND GEAR AT TIME OF ACCIDENT

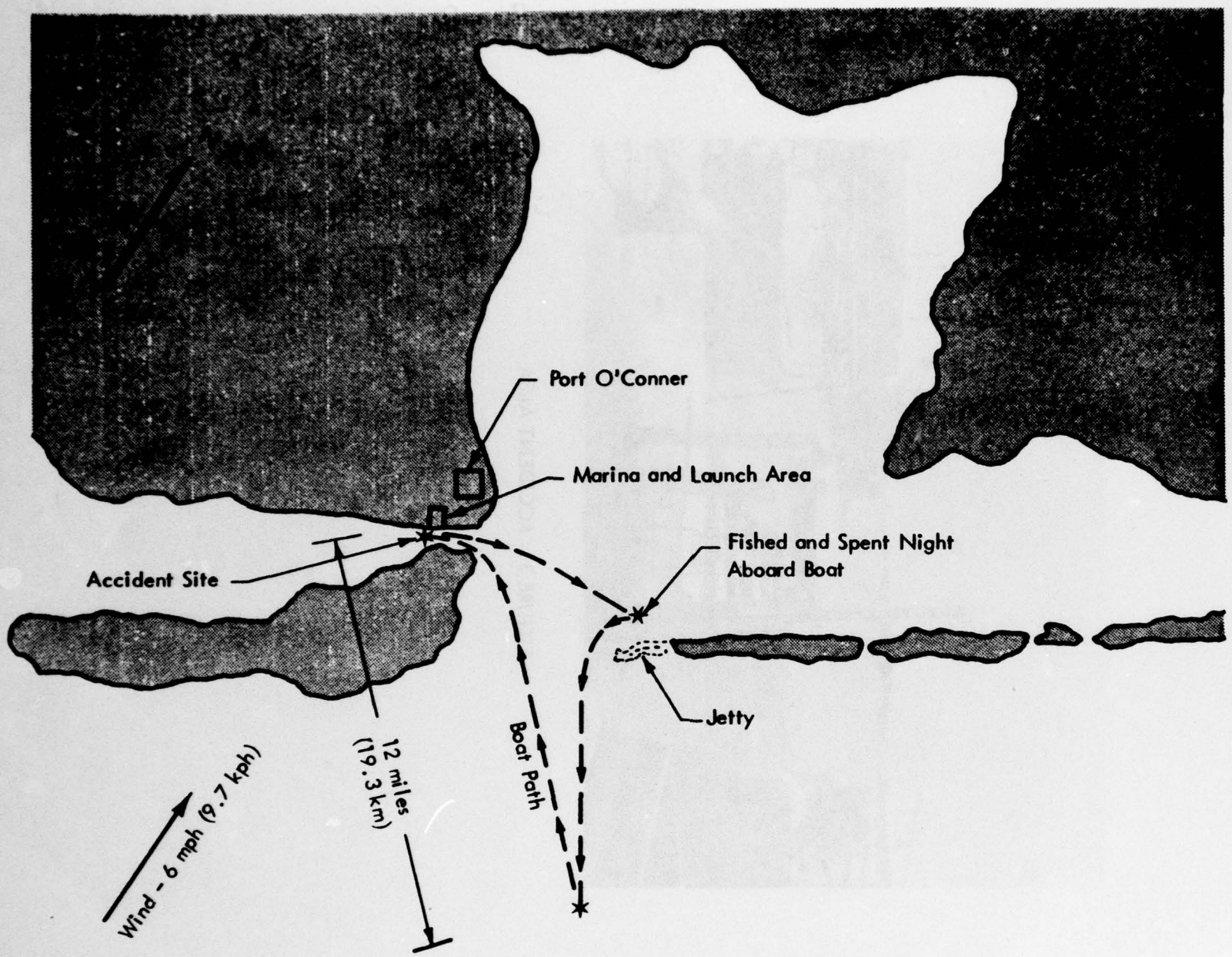


FIGURE 2. SKETCH OF ACCIDENT AREA

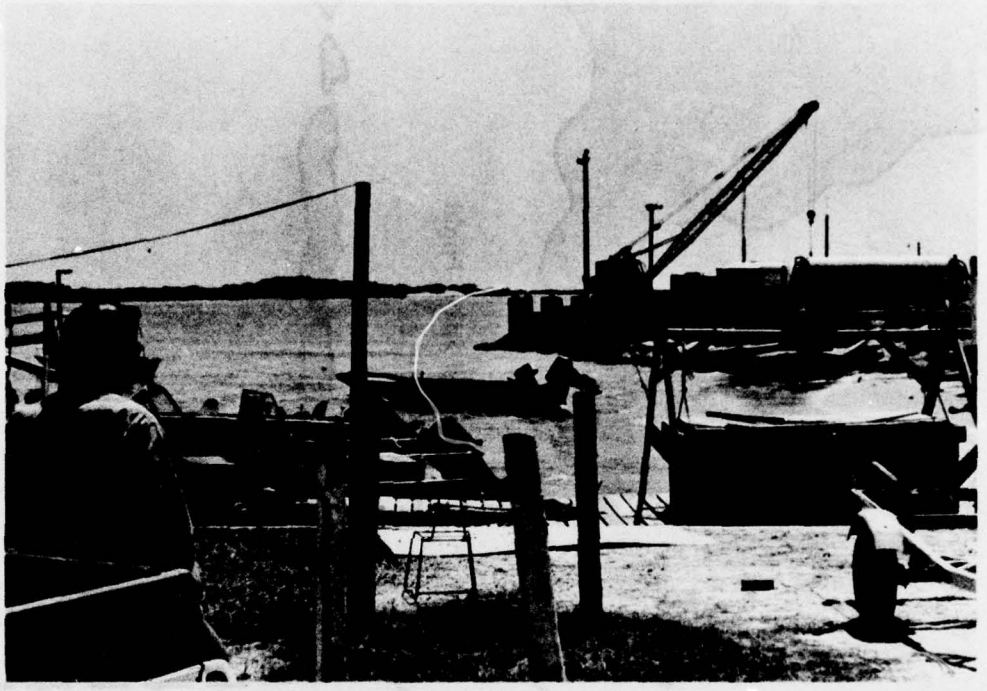


FIGURE 3. ACCIDENT AREA

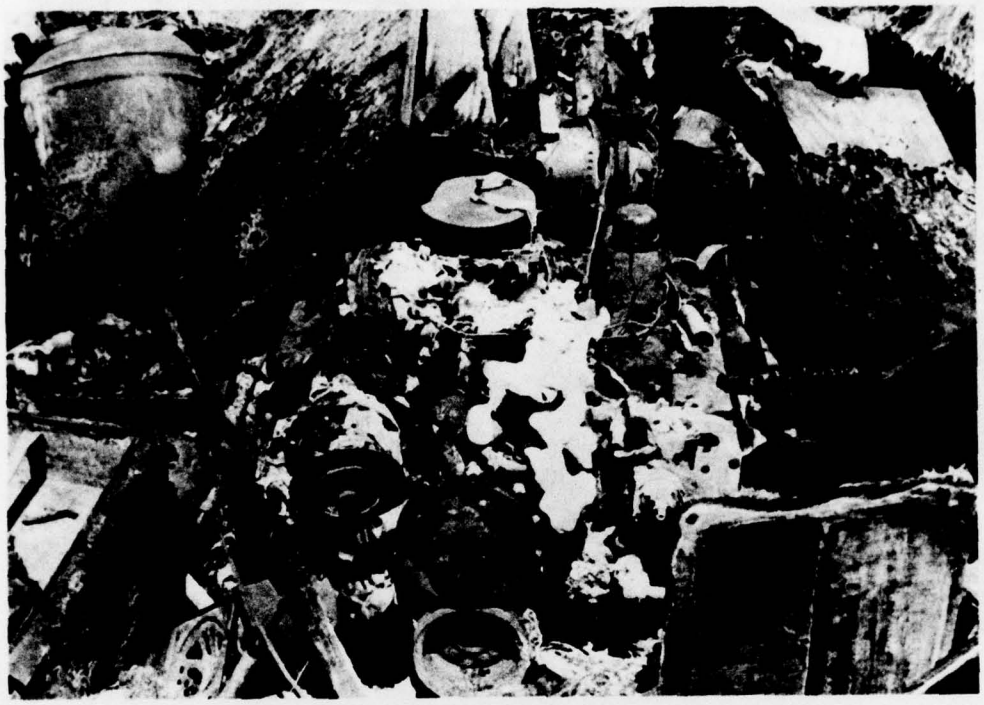


FIGURE 4

FIGURE 5

FIGURE 6

FIGURE 7

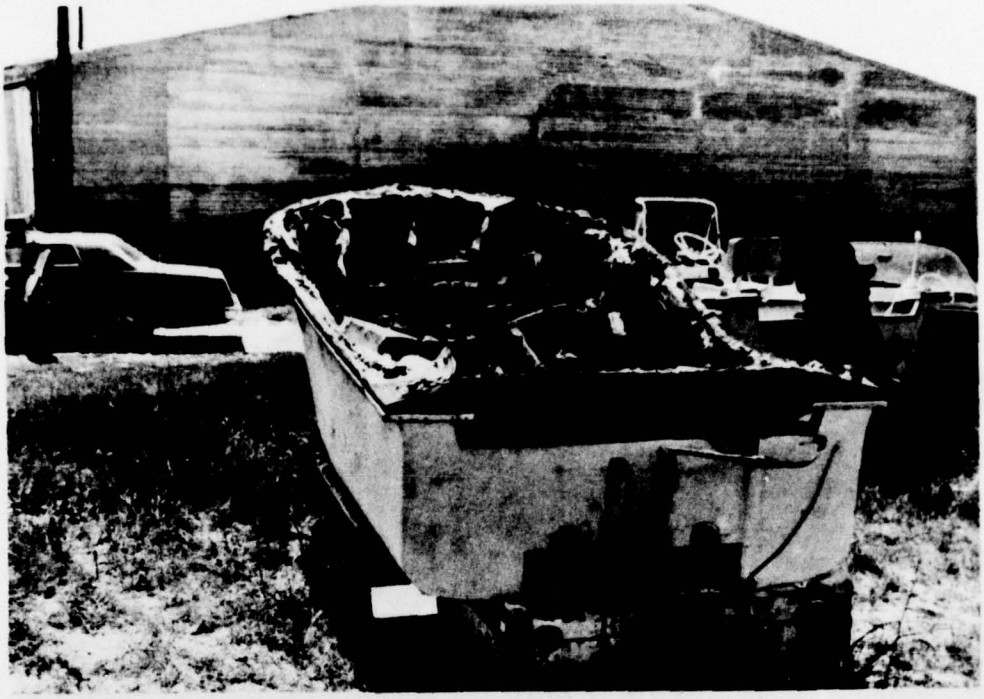


FIGURE 8

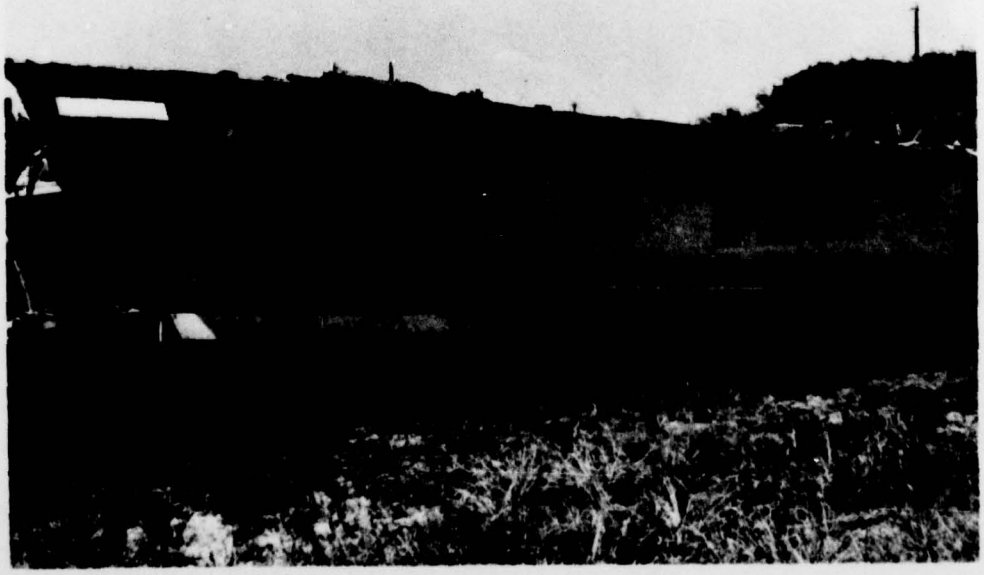


FIGURE 9

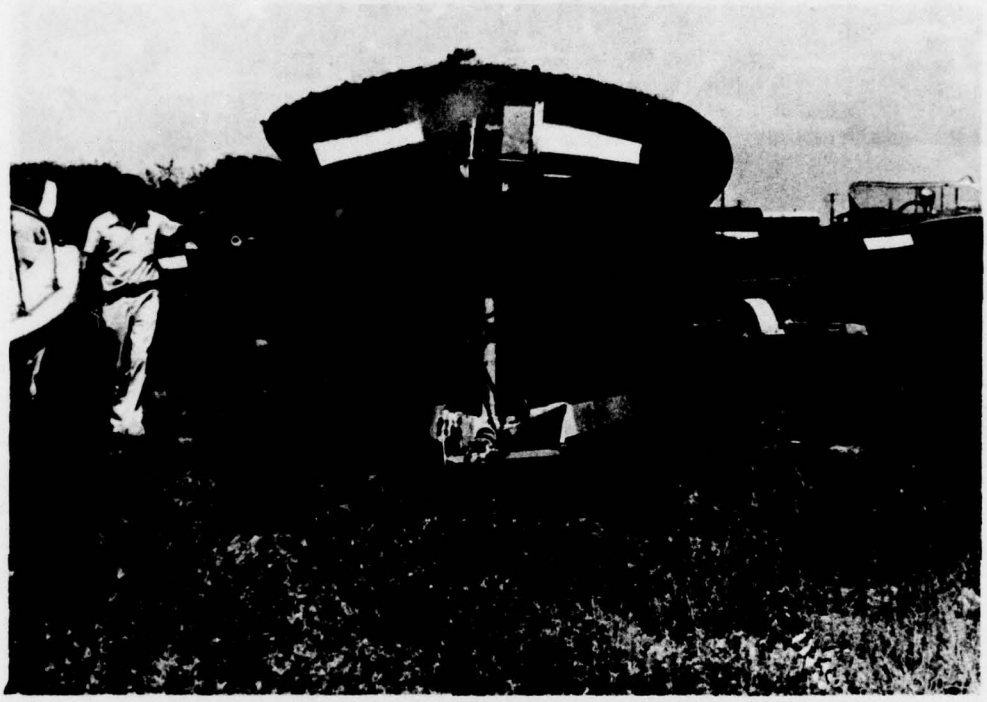


FIGURE 10

*U.S. GOVERNMENT PRINTING OFFICE: 1977 728-662/1263 1-3