TECHNICAL REPORT
NADC-79169-60

LIGHTWEIGHT EMERGENCY FLOTATION SYSTEM FOR THE CH-46 HELICOPTER

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FEBRUARY 1981

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Prepared for
NAVAL AIR DEVELOPMENT CENTER
Warminster, Pennsylvania 189

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Warminster, Pennsylvania 18974

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Helicopters are subject to roll-over and sinking within a minute of being forced down in sea states of 2 or greater. Crew egress is difficult and many drownings occur. Boeing was awarded a contract by NADC to develop a lightweight, automatically deployed flotation system to remedy the situation. An inovative system was designed which employs water scoops attached to 2 floats providing substantially increased stability for negligible weight. The concept was proven in wave tank tests and by full scale float and deployment system demonstrations.

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PREFACE

This document was prepared for the Aircraft and Crew Systems Technology Directorate (60) of the Naval Air Development Center (NAVAIRDEVCEN), Warminster, Pennsylvania, by the Boeing Vertol Company under Contract N62269-79-C-0707. The contract period was from September 1979 through January 1981. The purpose of this contract was to design, fabricate, and demonstrate one (1), lightweight, emergency flotation system for the H-46 helicopter which will provide emergency flotation and water stability.

The project is part of a more comprehensive Navy program "Helicopter Aircrew Survivability Enhancement Program" (HASEP) whose objective is the integration of newly developed safety systems into currently operational helicopters. Included in the safety systems are crashworthy troop seating, emergency flotation, crashworthy cargo restraint and automatically deployed life rafts. This project is limited to the development of an emergency flotation system.

This effort focused on the problems of providing an emergency flotation system which provides stability and flotation for the CH-46 helicopter when forced down on the water in conditions up to sea state 5. Minimum weight and system reliability are crucial factors considered.

The author gratefully acknowledges the counsel and deep involvement of Mr. Bill Wiesemann, NADC Project Technical Monitor, who contributed significantly to this development program. Appreciation is extended to Sam Martin, project engineer of ILC-Dover, for his cooperation and diligent effort during float fabrication and testing.

SUMMARY

Introduction

The H-46 helicopter was designed to operate on water and remain afloat in wave heights up to 2 feet with the rotors shut down. Water integrity depends on all hatches and the ramp being closed prior to landing. Water landing capability has been demonstrated in flight test to the pilots operating manual envelope of 480 ft./min. rate of descent at touchdown speed of 20 knots or 240 ft./min. at 30 knots. Historically, H-46 helicopters have made emergency and uncontrolled landings with hatches open and/or exceeding the flight envelope. The emergency landings have occurred because of power failures, mechanical failures, pilot disorientation at night and other uncontrolled factors. In these cases the aircraft usually rolls over inverted, fills with water and sinks within 1 to 2 minutes. Evacuation of crew and personnel is extremely difficult under these conditions and a number of drowning fatalities have occurred. Exhaustive studies of the problem have been conducted by the Naval Safety Center at Norfolk, Virginia, NADC Warminster, Pennsylvania, Boeing Vertol Company and others. The conclusion of these studies is that the only effective way to save these personnel is to provide emergency inflatable flotation which will keep the aircraft on the water surface for sufficient time to effect orderly evacuation.

The purpose of this contract is to remedy this situation by developing a lightweight, emergency flotation system for the H-46 helicopter which will significantly reduce, if not eliminate loss of life from drowning, and permit recovery of the aircraft in most, if not all survivable water-entry situations.

The initial phase included performance of wave tank tests using a 1/8 scale model of the H-46 helicopter. Various auxiliary flotation configurations were tested. A two float configuration with water scoops was selected as the optimum configuration. The 2 float system weighed the least and the scoops when filled with water increased stability significantly.

Full scale floats were fabricated using a kevlar fabric which is resistent to strength degradation from repeated folding. Pressure burst tests were conducted. Demonstrations of the complete system were performed which tested the pneumatic inflation system, the automatic water sensing initiation system, the frangible pod opening system and the float installation and assembly.

Conclusions

Basic design features of the float system were proven. Automatic initiation of the system using the water pressure sensor functioned properly, causing the squibs to fire and the nitrogen cylinders to discharge into the float. The frangible pod hinge sheared properly when both cells of the float were inflated simultaneously or when only one cell of the float was inflated. Problems were encountered with inflation time which was double the required time. Initial inflation pressures were inadequate due to the cooling of the gas as it expanded through the inlet ports. Pressures in the cylinders dropped to an unsatisfactory low level due to cold soaking at zero degrees F. ambient temperature. Leaks developed in the float due to load concentrations at points where attachment gussets terminated on the float.

After completion of contract testing the float vendor arranged a demonstration of a cool gas generator system to inflate the float. This system utilized two aspirations and achieved inflation of the float to 1 psig in 4 seconds. A larger cool gas generator could also be used for direct pressurization of the float.

A preliminary cost and scheduling analysis was conducted for the preliminary design of the float attachments which revealed that complex tooling would be required. Other float attachment methods were studied with the objective of reducing tooling costs and simplifying the load transfer from float girth attachments into the airframe.

Recommendations

As a result of the tests reported herein the following recommendations are made:

1. Continue development of float to airframe attachments to obtain maximum strength with a minimum load concentration on the airframe.

2. Conduct trade studies of alternate inflation systems, considering at least the following:

   1) weight; 2) external volume; 3) installation complexity and accessability; 4) rapid inflation requirements; 5) high and low temperature operating range; 6) reliability; 7) safety hazards; 8) inspection and servicing aboard Navy ships; 9) technical risks and; 10) non-recurring and production recurring costs.

3. Conduct preliminary mockups on the H-46 helicopter to determine inflation cylinder locations and interface with the floats.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont)

LIST OF ILLUSTRATIONS

LIST OF TABLES

INTRODUCTION

To date a total of 64 H-46 U.S. Navy and Marine helicopters have made emergency water landings: 47 have sunk, with a loss of 75 lives. Fifteen (15) of the 47 that sank have occurred since 1975 with a loss of 25 lives. U.S. Navy HC squadrons alone have lost 17 H-46's sunk with 27 fatalities. Nine of these 17 have sunk since 1975 with 16 fatalities. Water landings occur because of, (1) power failure; (2) pilot disorientation at night and in bad weather; (3) hitting obstructions on ships and subsequently falling overboard; and (4) mechanical failures of the rotor, drive, and flight control systems. Nearly all emergency water landings are forced landings since precautionary water landings are rare. Of these emergency landings it is estimated that approximately 50 percent of aircraft and personnel losses could have been prevented had adequate emergency flotation been provided. Over 90 percent of the H-46 aircraft that sank had at least one survivor, indicating that almost all of the water impacts are potentially survivable.

This program is for the design development and testing of an automatically deployed emergency flotation system to maintain flotation and stability for the aircraft when forced down at sea. The program is one of several development efforts under HASEP (Helicopter Aircrew Survivability Enhancement Program) for Navy helicopters.

Background

Helicopters are extremely unstable on the surface of the water due to the heavy transmissions, rotor hubs and engines located high in the aircraft, producing a high center of gravity. Typical scenarios for water landing accidents in helicopters include controlled landings in heavy seas with subsequent rotor blade contact with the water causing upset of the aircraft. Roll instability in high seas also causes rollover even after a successful landing and rotor shutdown. Rollover is even more likely in uncontrolled landings. During normal H-46 operations, hatches and windows are open and upon hard landings the lower plexiglass bubbles in the nose section frequently break. Watertight hull integrity is usually rapidly lost followed by or concurrent with the aircraft rolling over. The H-46 has very little buoyancy in the forward end which is an additional hazard when the aircraft rolls over and rapidly fills with water because the nose sinks first trapping personnel in the aft cabin. Under these conditions of the aircraft rolling over, rapidly filling with water and sinking nosedown, expecially at night it is nearly impossible for occupants to detach themselves from seat belts and walk-around harness, swim down to the forward escape hatches and push them outward against inrushing water and egress successfully. The design criteria for an emergency flotation system must take into account all of these factors.

Program Objectives

The objective of the program is to design and develop a lightweight emergency flotation system for the CH-46 helicopter which will significantly reduce if not eliminate the loss of life through drowning, and permit recovery of the aircraft in most if not all survivable water entry situations. These situations include controlled as well as uncontrolled water landings with aircraft entry into the water at any attitude, and consideration shall be given for safe and orderly egress of personnel from the aircraft in a flooded condition.

Scope

The program is to include design, development, and testing of a light weight flotation system. Testing was to include simulation of sea state 5 conditions using a wave making tank and a scaled model of the CH-46 with various float configurations. Studies of float installation on the CH-46 are to be made and the extent of structural modifications determined. Various methods of inflating the floats are to be evaluated. A full scale system is to be fabricated and demonstrated using various modes of initiation.

Basic Requirements

The contractor shall design, fabricate, and deliver one (1), light weight, emergency flotation system for the H-46 helicopter which will provide flotation and stability for H-46 aircraft in Sea State conditions as high as sea state 5. The system shall demonstrate as closely as possible the functional aspects of a prototype system. The flotation system shall comprise external pod-mounted, inflatable floats, in a two-float and/or four-float mode, capable of automatic, semi-automatic, and manual release and deployment, using a standard (compressed gas, only), or an aspirated (compressed gas with accessory air-aspirator valve) inflation system. The delivered flotation system shall be designed to simulate the H-46 geometry with adequate attachments for demonstrating deployment on one side of helicopter. Interface with aircraft electrical and sensor systems may be simulated, and qualification of components is not required. The intent of this effort is to demonstrate the proposed design concept, and to provide sufficient documentation for prototype development.

The light weight, emergency flotation system shall:

- Provide sufficient buoyancy to meet the maximum operational gross loading weight (approximately 23,300 pounds) for a downed helicopter, whether a two-cell or a four-cell system is adopted.

- Be constructed using the lightest components possible, commensurate with overall system efficiency and reliability.
- Minimize impairment of assigned missions.
- Be compatible with current and/or proposed survival systems.
- Be compatible with current and/or proposed modifications to the aircraft.
- Minimize learning requirements for crew members.
- Provide maximum system effectiveness with the current state-of-the-art.
- Be aerodynamically compatible with the aircraft.
- Be adaptable to other helicopter types.
- Represent, as closely as possible, production hardware.
- Have a Minimum Maintenance Malfunction Rate of 600 flight hours between failure.
- Have no Mission Single Failure Points that would cause mission abort (i.e., no flotation system failure shall compromise the safety of the crew or aircraft, while in flight).
- Allow for preventive and corrective maintenance using standard tools. The only regular organization level maintenance shall be checking the pressurization system for full charging.

Wave Tank Testing and Analysis Requirements

Using a contractor furnished 1/8 scale buoyant model of the CH-46 helicopter, reproducing as closely as possible the flotation characteristics of the full-size aircraft, wave tank analyses shall be conducted by the contractor using the facilities at the David Taylor Naval Ship Research and Development Center, Bethesda, Maryland.

The wave tank program phase shall be as follows:

- o The wave tank tests shall be conducted using (or simulating) miniature inflatables (built to the same scale as the buoyant model aircraft) to provide auxiliary buoyancy for the model aircraft.

- o Analyses shall be made to determine the auxiliary flotation necessary to maintain stability of the model helicopter up to an including simulated sea state 5 conditions. Maximum heel angle for calm sea conditions, and a combination of maximum heel angle and wave slope angle for sea state 5 conditions shall be determined.

- o Two versions of auxiliary flotation shall be used, one, a two-float, and the other a four-float system. The floats shall be located forward of the aircraft C.G. in the two-float configuration, and the floats shall be located two forward and two aft, in the four-float configuration.

- o Determinations shall be made simulating maximum gross weight conditions, using the model for the two-float and the four-float versions. Each configuration shall be evaluated with the model perpendicular to, parallel with, and at 45 degrees to the waves. Sea state conditions in the tank shall progressively be increased up to sea state 5 condition.

- o Determinations shall be made of the maximum sea state(s) for which stability of the model aircraft can be maintained for both flotation device configurations, and the findings shall be documented with motion picture film.

Design and Development Requirements

An analysis of all the wave tank data shall be made.

A prototype flotation system shall be designed and fabricated, based on the wave tank data, and the theoretical and demonstrated findings of the prior contractual efforts made in the helicopter flotation program, to date. The prototype system shall demonstrate:

- o The two-float system, if it is preferred to the four-float system, or
- o The four-float system, if it is preferred to the two-float system.

Both pressurization (inflation) systems, non-aspirated and aspirated, shall be evaluated and reported on, and one selected version shall be used to demonstrate operation of the prototype flotation system(s).

System Initation and Control Requirements

The, light weight, emergency helicopter flotation system shall include initiation and control components located on or near the aircraft's existing instrument panel, which shall provide the three modes of flotation system initiation, automatic, semi-automatic, and manual. The flotation system shall be demonstrated using each of these modes.

DESIGN DEVELOPMENT

Flotation System Configuration Design

Prior studies have shown that 4 floats were required for flotation and stability of the CH-46 helicopter. Spherical floats were recommended and tying these floats to the nose and main landing gears was proposed. Detail analysis of this system showed that it would be difficult to mount a container pod on the sponson to stow the aft floats. Carrying nitrogen supply lines to the aft floats was difficult and consideration of an aspirated inflation system was out of the question. Location of forward floats at the nose landing gear would interfere with the life raft stowage which is part of this HASEP development program. Weight and complexity of the 4 float system was also excessive.

A study was made of various methods of providing a 4 float system. Aside from the aft spherical floats (Figure 1) one configuration provided floats under the sponsons with the stowage pod also located under the sponson (Figure 2). Analysis of the 4 float system using spherical floats showed that adequate righting moment was provided (Table 1). However, the floats mounted under the sponson provided only marginal stability due to the closeness of the float installation to the centerline of the aircraft and the upside float remaining submerged added to the overturning moment.

A 2 float system was investigated to reduce weight, complexity of inflation installations and cost. It was found that the forward floats, located just aft of the entrance door, if increased in size slightly to 140 ft^3 would provide adequate floation for the maximum gross weight of the aircraft. Static stability however, was not adequate for the lower gross weights which are more critical for rollover (Table 1). Center of gravity is higher in lighter loaded aircraft and a higher overturning moment develops in a roll.

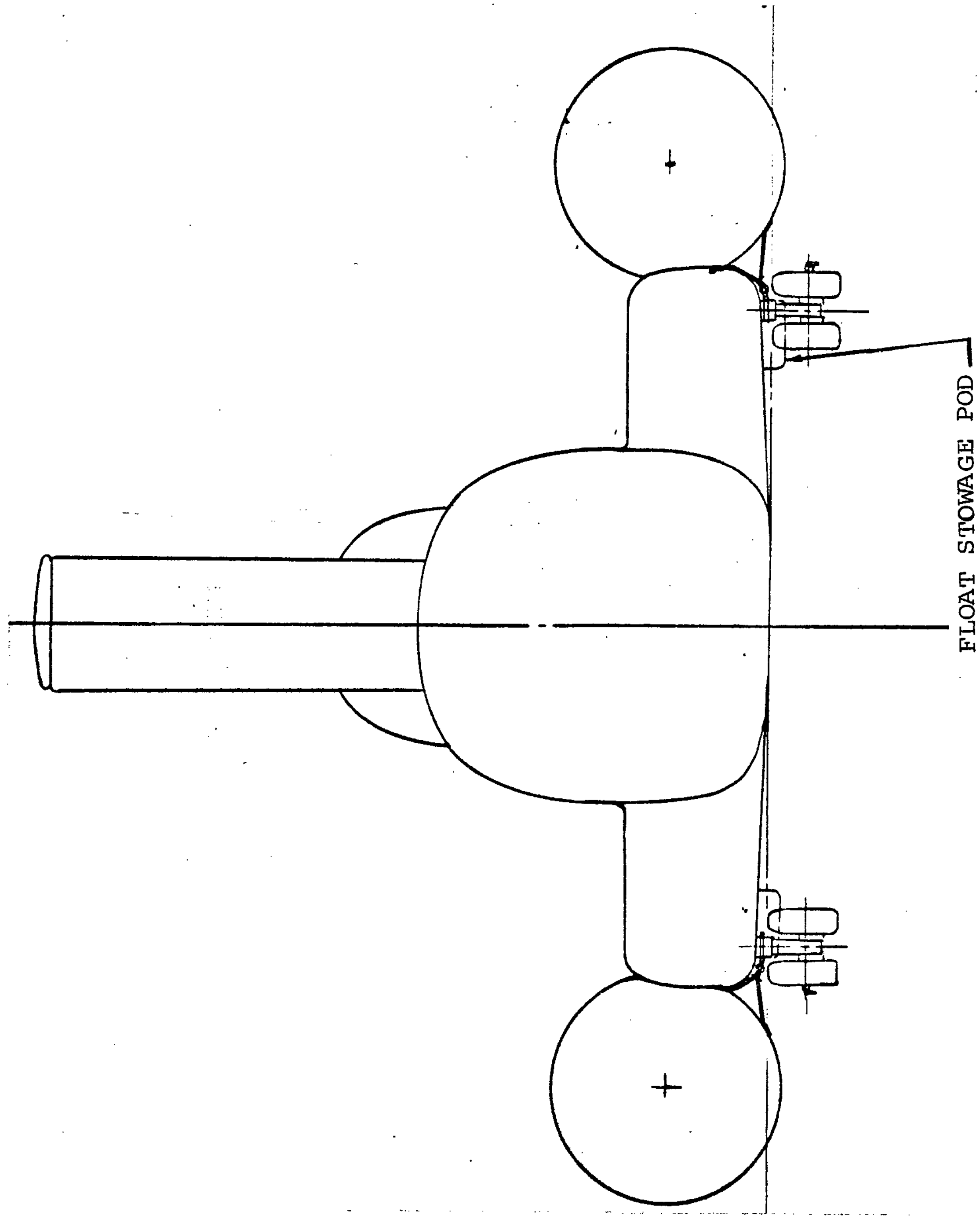


Figure 1. Spherical sponson float attached to landing gear.

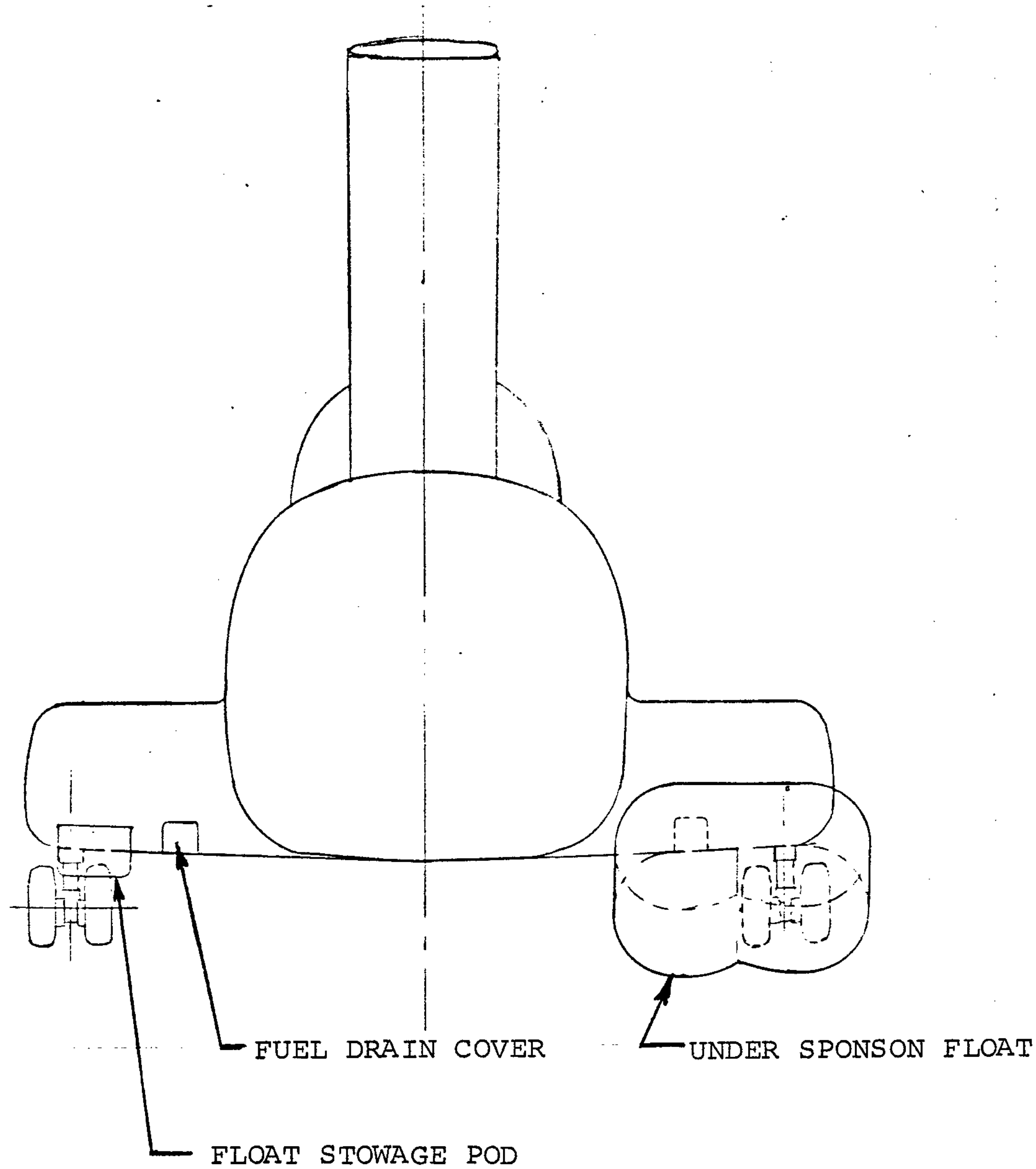


Figure 2. Under sponson float system.

TABLE 1. STABILITY IN SEA STATE 5 17° WAVE SLOPE - 40° ROLL

CONDITION AND GROSS WT. LB.	OVERTURNING MOMENT-IN. LB.	RIGHTING MOMENT - IN. LB.				TOTAL OVERTURN MOMENT	TOTAL RIGHTING MOMENT	BALANCE MOMENT IN. LB.
	AIRCRAFT WEIGHT	FWD FLOAT	AFT FLOAT	SPONSON	SCOOPS			
4 FLOATS 23,000	345,000	230,400	268,800	1,703	-	345,000	500,903	+155,903
4 FLOATS 13,675	396,144	230,400	268,800	1,703	-	396,144	500,903	+104,759
2 FLOATS 13,675	396,144	340,480	-	1,703	-	396,144	342,183	- 53,931
2 FLOATS SCOOPS 13,675	396,144	340,480	-	1,703	204,000	396,144	546,183	+153,039
2 FLOATS SCOOPS 16,697	367,334	340,480	-	1,703	204,000	367,334	546,183	+178,849
2 FLOATS SCOOPS 23,000	345,000	340,480	-	1,703	204,000	345,000	546,183	+201,183

NOTES: 4 FLOATS - 100 CU. FT. FWD, 60 CU. FT. AFT
2 FLOATS - 140 CU. FT. FWD
SCOOPS - SEA WATER CAPACITY 2,000 LB. EACH SIDE

To maintain the lighter weight of a 2 float system, an innovative design of a waterscoop concept attached to the outboard sides of the floats was developed (Figure 3). Analysis of the righting moment provided by the scoops, as they picked up seawater in a roll, showed that the righting moment was adequate for sea state 5 (Table 1 and Figure 4). The scoops would also aid in counteracting the roll moment produced by blades striking the water. Scoops would be of water tight fabric similar to the float material. Volume of the scoops would be approximately 234 gallons each side of the aircraft which would weigh 2000 pounds.

Flotation System Design Considerations

Helicopters are particularly vulnerable to rollover on the surface of the water due to their high center of gravity. The heavy transmissions, rotor heads, rotors and engines located high on the aircraft contribute to the high center of gravity. Once the aircraft rolls over, water quickly enters open hatches and other non-sealed openings in the top of the aircraft. Although the H-46 helicopter will float for an indefinite period of time on the surface of relatively calm water, a number of factors can cause it to roll sufficiently to move the center of gravity to a point where the overturning moment exceeds the buoyant righting moment. Several factors can cause the aircraft to roll past the point of adequate restoring moment, these are as follows:

1. Wave slope
2. Breaking wave force
3. Rotating rotor blade contact with the water
4. Paddle effect of non-rotating rotor blades in waves
5. Abnormal aircraft impact attitude
6. Wind

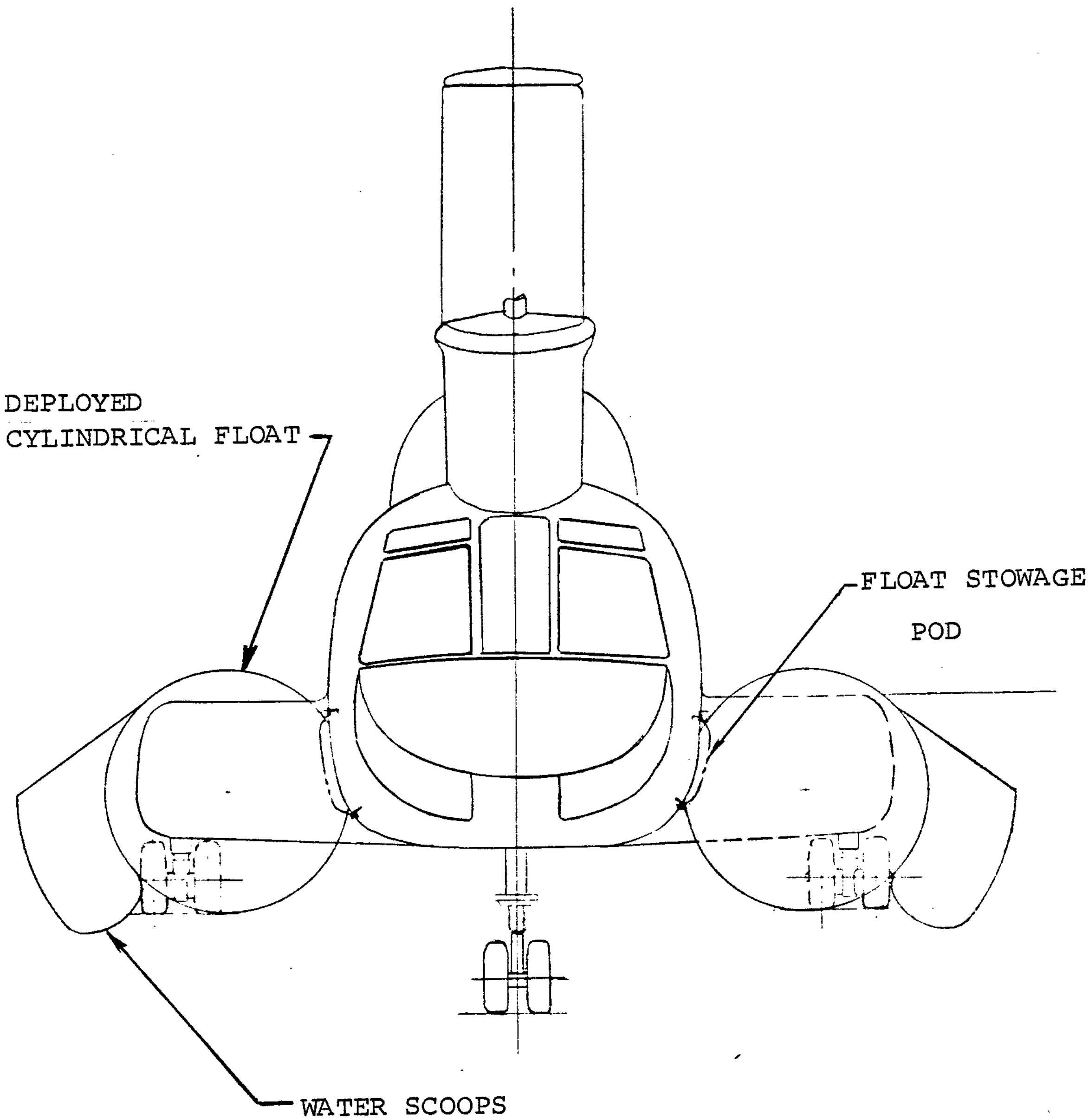


Figure 3. Forward floats with water scoops.

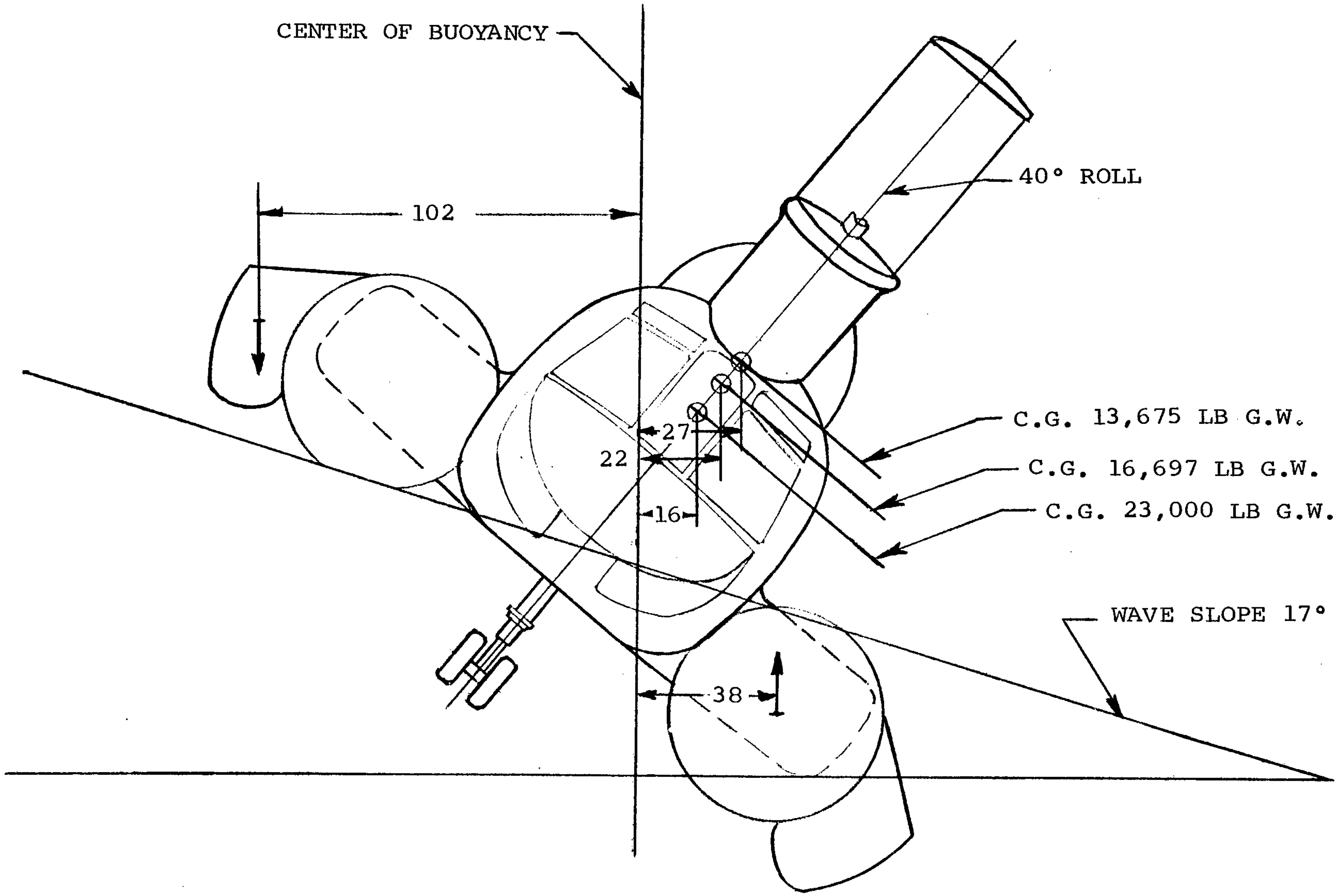


Figure 4. Aircraft with forward floats and water scoops on sea state 5 wave slope.

One or more of these factors are usually present to contribute to aircraft rollover. A single factor is not usually sufficient to cause rollover. Regular waves alone usually do not change the angle of the aircraft and displace the center of gravity sufficiently to cause rollover even in high sea states. The angle of the wave slope does not vary significantly over a range of several sea states. Table 2 shows ratio variation for sea states 2 through 6 using the average 1/10th highest wave and wave length for each sea state. Wave height to length ratio decreases from one to fourteen for sea state 2 to one to ten for sea state 5 and to one to nine for sea state 6. Wave angle increases only approximately 3 1/2 degrees between sea state 2 and sea state 5.

Wave Tank Testing

Tests were conducted at the Maneuvering and Sea Keaping Facility (MASK) a wave making tank at the David Taylor Naval Ship Research and Development Center, where random waves were produced simulating sea states 3, 4 and 5. A 1/8th scale model of the CH-46, ballasted and dynamically ballanced was used as the test specimen. The five flotation configurations tested were as follows:

1. Inherent aircraft flotation (no floats added)
2. Two fwd 140 ft^3 floats with water scoops
3. Four floats - 113 ft^3 fwd, 50 cu. ft. aft spheres
4. Four floats - 113 ft^3 fwd, 50 cu. ft. under aft sponsons
5. Two fwd 113 ft^3 floats

Conditions under which the above configurations were tested were as follows: (not all conditions were tested for each configuration).

1. Minimum gross weight (14,000 lbs)
2. Maximum gross weight (22,000 lbs)

TABLE 2 - SEA STATE CHART

SEA STATE	WAVE HEIGHT-FT. AVG. 1/10 HIGHEST	AVERAGE WAVE LENGTH-FT.	HEIGHT TO LENGTH RATIO
2	3.7	52	1:14
3	5.8	71	1:12
4	8.7	99	1:11
5	16	160	1:10
6	23	212	1:09

3. With hull integrity
4. Without hull integrity (hull flooded)
5. Without wind
6. Wind simulated by offsetting ballast

A total of 52 test runs were made including calibration runs. Sea states 3, 4 and 5 were simulated. The majority of the tests were conducted with the aircraft beam-on to the waves. This position was maintained by prodding the aircraft with a pole. If allowed to float free, which was permitted in some of the tests, the aircraft would position itself with stern quarter to the waves with added floats and bow quarter to the waves with no floats.

Baseline Test - No Floats

The first series of tests were performed on the test specimen with no emergency flotation added. The model simulated a minimum gross weight, 22,000 pound aircraft. Five runs were made beginning with sea state 2 and progressing to sea state 4. Testing began allowing the aircraft to float free. It swiveled to a bow-on attitude with the waves which is less critical than a beam-on attitude. In the subsequent tests the model was prodded into the more critical beam-on attitude. A rotor blade is shown dipping into a wave in Figure 5. After approximately 5 minutes of sea state 4 testing the aircraft capsized (Figure 6). The aircraft tended to roll into the waves and capsized in that direction.

Two Float Tests - Two Forward With Water Scoops

The second series of tests were conducted with 140 ft^3 forward floats having water scoops and located just aft of the forward cabin door. The scoops were found to be set too high and were only half full of water. In spite of this situation the model was extremely stable in tests from sea state 3 through sea

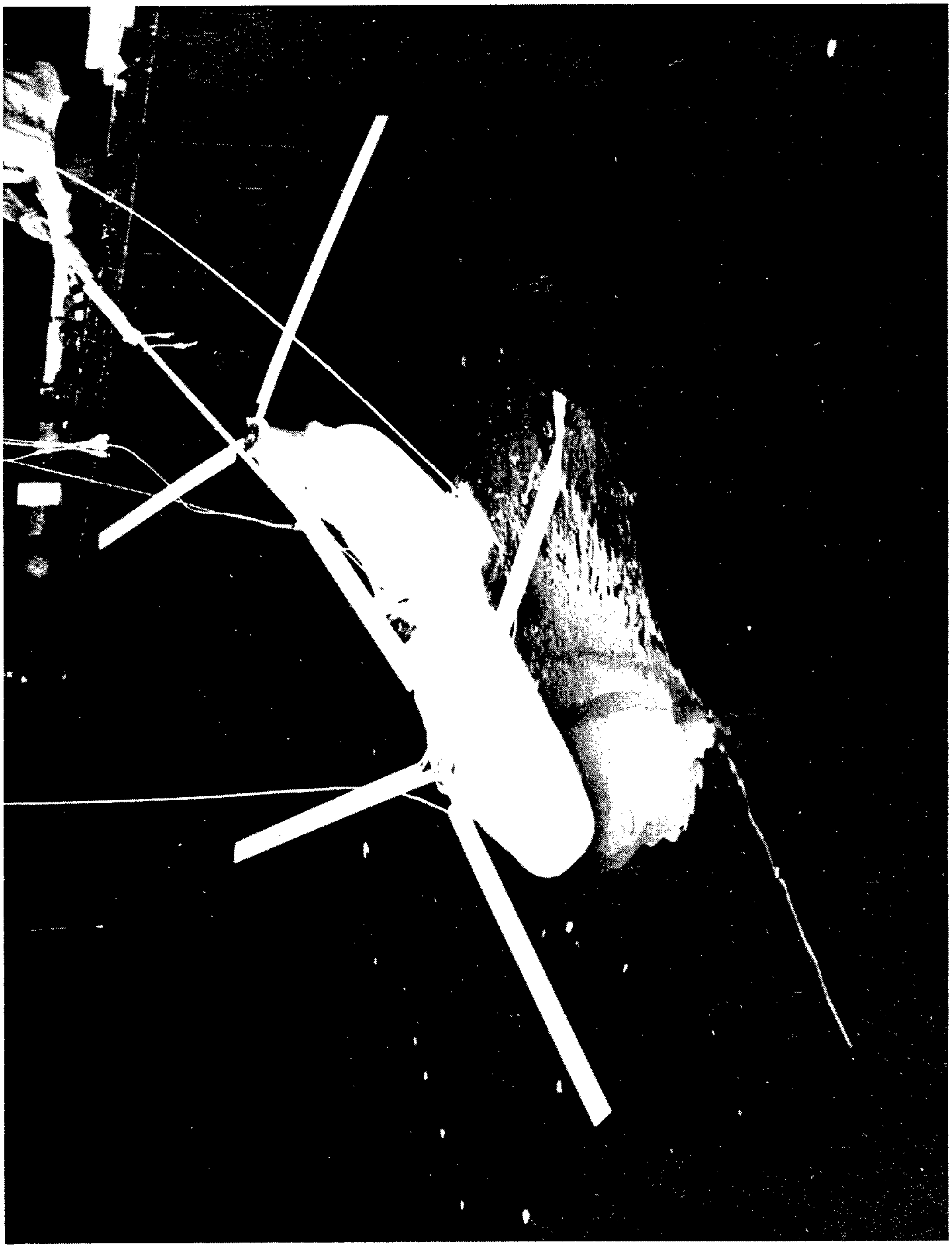


Figure 5. No added flotation, rotor blade dips into wave.

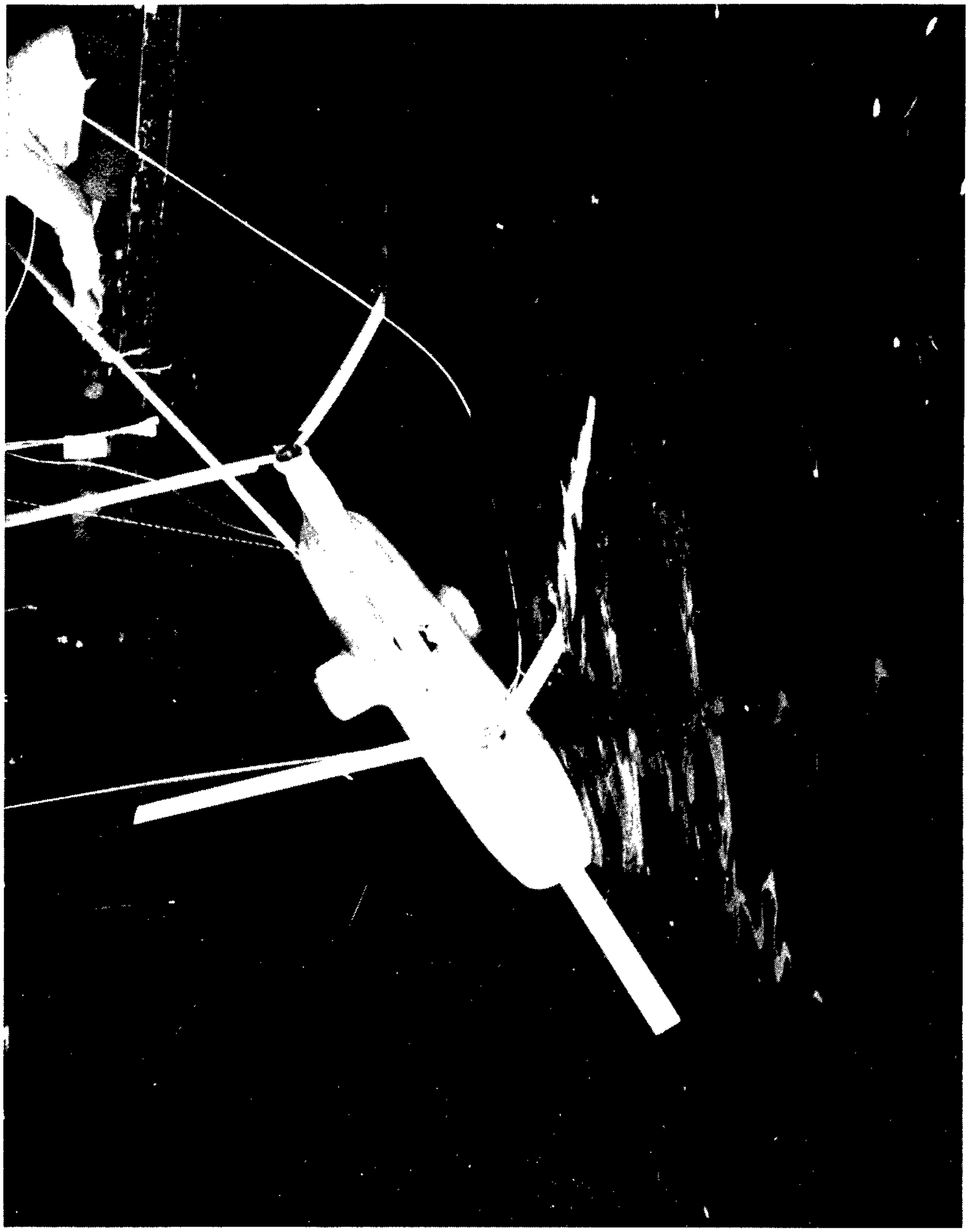


Figure 6. No added flotation, capsize in sea state 4.

state 5, the limit of the wave maker's capability. Free floating tests were performed as well as beam-on tests. This attitude was maintained by prodding. When free floating, the aircraft swiveled to a stern-on attitude. In the beam-on attitude breaking waves rolled over the top of the aircraft but the combination of floats and water scoops maintained stability. Breaking waves tended to cause the aircraft to roll away from the waves when floats are installed.

Four Float Tests - Two Forward and Two on Sponsons

The next float configuration tested was a pair of 113 ft^3 cylindrical floats mounted forward and a pair of 54 ft^3 spherical floats mounted aft attached to main landing gear, outboard of the stub wing sponsons (Figure 1). Hull integrity was maintained during the tests in sea states 4 and 5. Test results showed this configuration to be less stable than the 2 float and water scoop system. The aft spherical floats were 90 percent out of water due to the inability of mounting them lower on the stub wings. Therefore, the amount of flotation contributed by the floats was minimal and also, they did not contribute significantly to stability. For these reasons, the configuration is unacceptable.

Four Float Tests - Two Forward and Two Under Sponsons

Tests were conducted in sea states 4 and 5 using 113 ft^3 cylindrical floats in the forward position and 54 ft^3 cylindrical floats in the rear, mounted under the stub wing sponsons (Figure 2). These tests were conducted with hull integrity and the results showed less stability than the 2 float and water scoop system. In addition the floats under the stub wings raised the stern to the extent that the forward rotor blade dipped frequently into the water. A rotating blade contacting the water is the principal cause of helicopter rollover. The blade dipping problem plus the nose low attitude, which would impede egress from a flooding helicopter, makes this configuration unacceptable.

Two Float Tests - Two Forward

Additional tests were run in sea states 4 and 5 with only the forward floats, the rear floats removed (Figure 7). Hull integrity was maintained. However, had the hull been flooded the 113 ft^3 forward floats would be insufficient to maintain flotation at 23,300 gross weight. The test results were similar to the previous tests with the added spherical floats. This configuration is unacceptable however because of insufficient buoyancy available and insufficient righting moment to overcome the overturning moment caused by rotor blades striking the water and high sea states.

Baseline Tests - No Floats (14,000 Pound Gross Weight)

The basic aircraft without auxiliary flotation was retested in sea states 3, 4 and 5 at the low gross weight of 14,000 pounds. The aircraft was more stable at the lower gross weight because the stub wing sponsons sat higher out of the water. As the aircraft rolled, the submerging sponson provided more buoyancy and a corresponding righting moment. Rollover, however, occurred in sea state 5.

Two Float Test - With Water Scoops - Simulated Wind

At the low gross weight retests were made of the 2 float configuration (140 ft^3 with water scoops). The water scoops were lowered to assure filling to capacity with water (Figure 8). An attempt was made in this series of tests to simulate wind which had not been simulated in previous tests.

Figure 7. Two forward floats of 113 cu. ft.

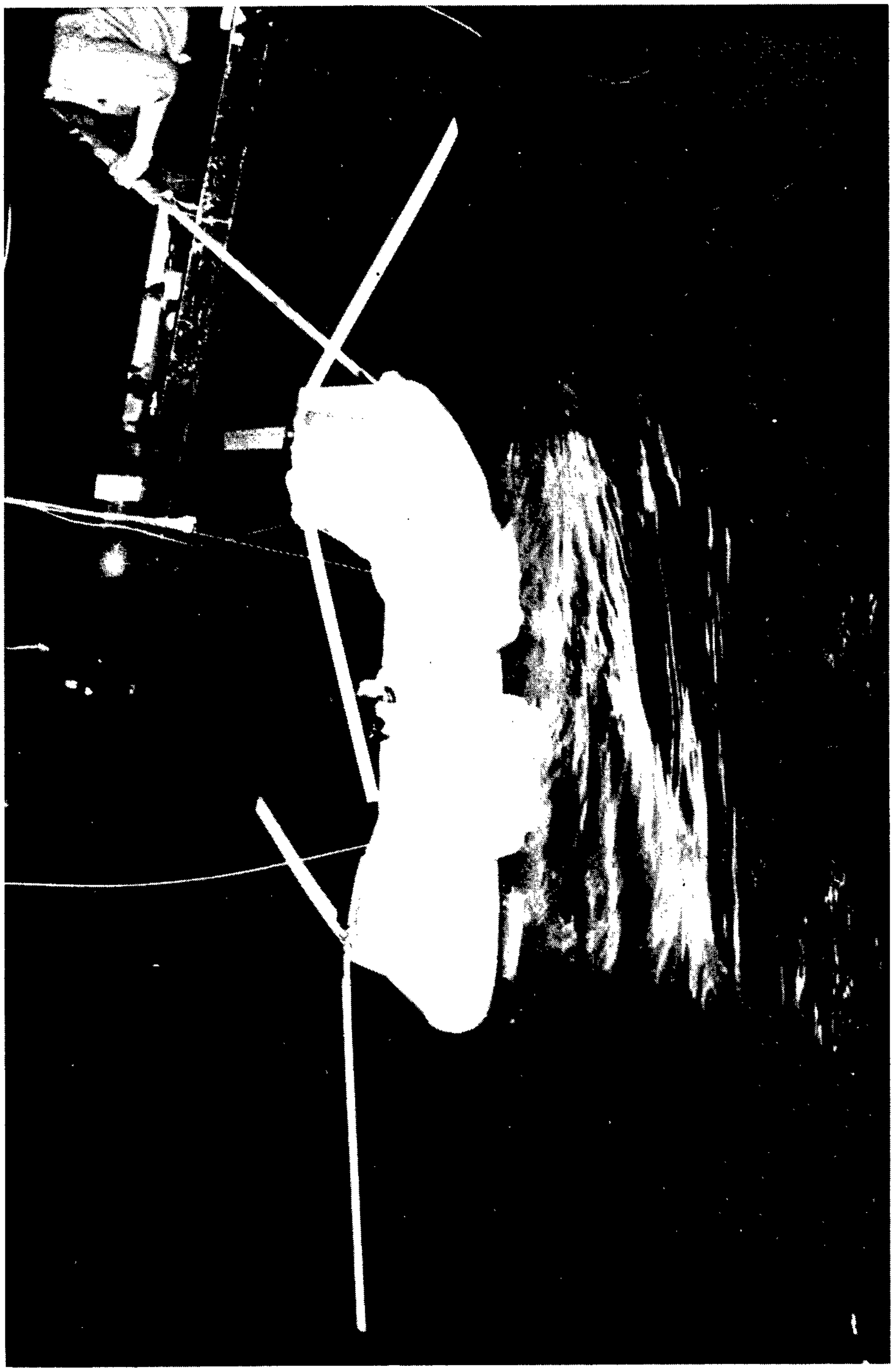


Figure 8. Two 140 cu. ft. forward floats with water scoops.

A weight was hung on the side of the aft pylon (vertical fin) which caused the aircraft to list in the down wave downwind direction. As the aircraft tends to roll away from the waves this list is a more critical situation. Water can be seen spilling from the scoops as the aircraft rolls (Figure 9). Excellent stability was maintained by the 2 float system with water scoops. All tests were conducted in sea state 5 with no roll over or capsizing.

During the second run, the upwave float ruptured. Imminent roll over was expected, however, stability was maintained by the righting moment caused by the water in the water scoops on the down wave float that remained inflated. Also, motion damping was apparent from the water scoops in the deflated float. At this point the two 140 ft^3 float system with water scoops was selected as the choice system and all subsequent tests would be with this system.

Two Float Tests - Light Gross Weight - Flooded

Weights were removed from the model to simulate a light gross weight. A hole was drilled in the bottom so that water could freely enter the hull. The model was placed in the water and submerged until the water level in the aft end came to a point just above the aft stubwings. These sponsons no longer contributed to stability. Tests at sea state 5 showed that flotation and stability was maintained by the 2 float system with water scoops.

Two Float Tests - 22,000 Pound Gross Weight - Flooded

Weights were added to the model to simulate a max. gross weight of 22,000 pounds. Placing the aircraft in the water it submerged until the water level rose to the engines at the top of the aft fuselage (Figure 10). The nose projected above the

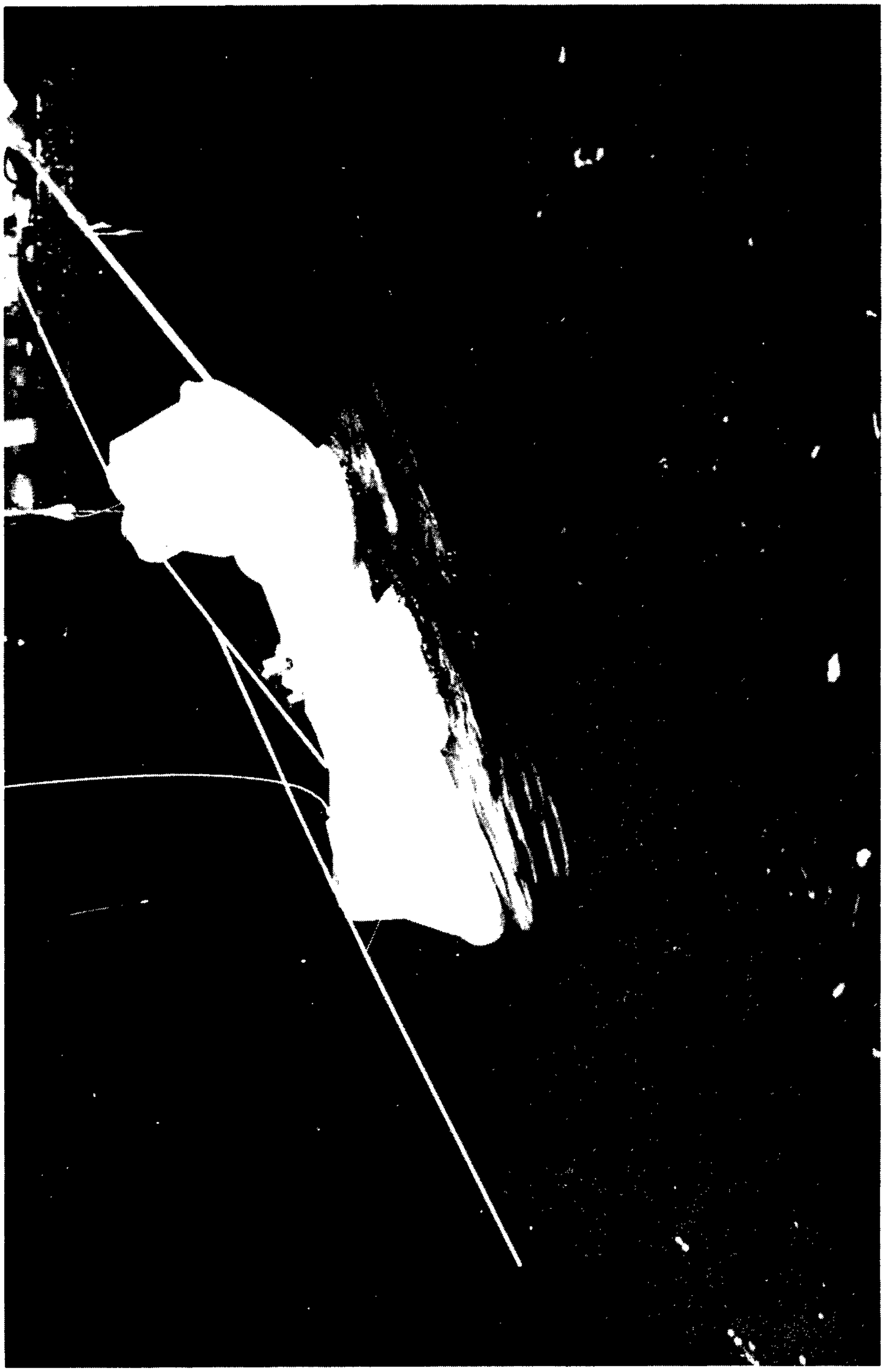


Figure 9. Water scoops working as water spills.

Figure 10. Aircraft at maximum gross weight, floating with hull flooded.

water. Wave tests were conducted at sea states 3, 4 and 5. Due to the low profile of the submerged aircraft and the mass of water inside the hull, maximum stability was maintained even in the worst wave conditions. The 2 floats, each at 140 ft^3, appear to be adequate to float the aircraft (Figure 10).

Simulated Towing Tests

The last series of wave tank tests simulated towing a flooded aircraft at various speeds, in various sea states. A minimum gross weight aircraft was used assuming that the aircraft would be unloaded prior to towing. Tests were conducted in sea states 2, 3 and 4 at speeds of 3 and 6 knots. Towing tests were conducted with the forward rotor blade pointing forward. At 3 knots the aircraft was successfully towed in sea states up to 4. However at 6 knots the forward blade dug in and the aircraft was pulled under the water.

Wave Test Conclusions

The following conclusions were reached as a result of wave tank testing.

1. The basic CH-46 capsized in sea state 4 at 22,000 pound gross weight and in sea state 5 at 14,000 pound gross weight. Wind and turning rotor impact with waves were not simulated but if present would considerably reduce the sea state in which stability could be maintained.

2. A pair of floats with water scoops attached and mounted at the forward end of the cabin, aft of the forward door, provided excellent stability and flotation for low to high gross weight and with and without the hull flooded. This configuration will hold the nose above the water in most conditions and probably when the aircraft is inverted.

3. Stability was maintained after collapse of one float through the assistance of the water filled scoops on the remaining good float in sea state 5.

4. A flooded aircraft is substantially more stable than a floating aircraft in high sea states.

5. A free floating H-46 helicopter (no wind) with forward floats turns aft quarter into the waves while the helicopter without floats turns the forward quarter toward the waves.

6. The CH-46 with floats tends to roll away from the waves while the aircraft without floats tends to roll into the waves and the waves wash over the sponsons and up the rotor blades.

7. Floats mounted to the rear in the sponson area raises the aft end causing forward rotor blades to become closer to the water and subjects the blades to frequent dipping in the water and therefore more prone to roll over if blades are turning.

8. Tow tests were discontinued due to time limitations. However, it is concluded that the tendency for the nose and forward rotor blade to dig into the waves could be reduced by towing from the landing gear rather than a point near the forward rotor, which was used. Repositioning the forward rotor blade from a direction straight forward to 60 degrees from the centerline would remedy the blade dipping problem.

The conclusion reached from the test results is that the two 140 ft^3 float system with water scoops provides adequate stability for sea state 5 conditions and sufficient flotation for a flooded H-46 at high gross weight.

FLOTATION SYSTEM DETAIL DESIGN

Selected System

The flotation system selected consists of a float mounted on each side of the aircraft just aft of the forward entrance hatches. Water scoops attached to the sides of the floats each fill with 2000 pounds of water to provide a righting moment for when the rotor blades strike the water and to maintain stability in high sea states. The floats are stowed in pods approximately 3 in. deep, 21 in. high and 100 in. long located just below the windows. Two systems are being considered, a direct pressure system (direct blowdown) and an aspirated system. Nitrogen or a cool gas generator could be used for either system. The pressurization system is initiated by electric squibs activated by direct action of the crew throwing a switch while the system is armed or by an automatic mode which activates the system when armed and when a water sensor senses the aircraft is in the water. As the floats begin to inflate, the pressure builds up causing the frangible hinge to release the pod cover. Full inflation is expected to require approximately 7 seconds.

Float Design

The float is constructed of polyurethane coated Kevlar fabric. The Kevlar is woven using a newly developed twist technique which greatly reduces the problem of strength degradation experienced with previous Kevlar fabrics when it is repeatedly folded. This material, used to construct the float, weights 10.05 ounces per square yard. Strength tests were conducted by pulling strips of the material from the lot used to make the floats. The results are as follows:

Float Material Characteristics

Tensile (strip method)
Warp - 498 lb/in. (avg)
Fill - 480 lb/in. (avg)

Tear (tongue method)
Warp - 81.3 lb.
Fill - 79.9 lb.

Tensile (after 10-180° Hard Folds)
*Warp - 434 lb/in. (avg)
*Fill - 382 lb/in. (avg)
*All samples failed at crease.

Coating Adhesion (RF Seal)
Face to Face - 22 lb/in. (avg)
Back to Back - 22.8 lb/in. (avg)

Coating Adhesion (UR1087)
Face to Face - 30.1 lb/in. (avg)
Back to Back - 30.8 lb/in. (avg)

Air Permeability - .37 L/m^2/day

Scoop Material Characteristics

Description - Reeves Style 18298 Kevlar with a wash coat of Polyurethane

Weight - 7.39 oz/yd^2

Tensile - (Strip Method)
Warp - 498 lb/in (avg)
Fill - 400 lb/in (avg)

Tear - (Tongue Method)

Warp - 102.8 lb. (avg)

Fill - 93.1 lb. (avg)

Tensile (after 10-180° Hard Holds)

*Warp 442 lb/in (avg)

*Fill 338 lb/in (avg)

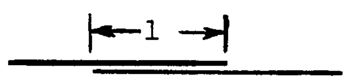
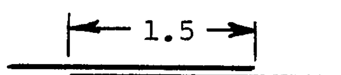
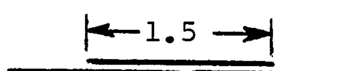
*All samples failed at crease.

Seam Evaluation

Material - Reeves Style 18297 Polyurethane Coated Kevlar

Method of Seaming - Dielectric Seal

Test Method 1 inch Grab

	SEAM		FAILURE (LBS)
#1		LAP	300 AVG
#2		LAP	315 (AVG)
#3		BUTT TAPE	620 (AVG)

Test Method 1 inch Cut Strip

#1	(Same As Above)	287 (AVG)
#2	"	410 (AVG)
* #3	"	550 (AVG)

* Indicates seam type chosen for flotation bag fabrication.

Float Configuration

The float is cylindrical in shape, approximately 58 inches in diameter and 100 inches long. A bulkhead of the basic float material is placed in the center, forming 2 airtight cells or compartments. Puncture of one compartment will result in the second compartment increasing in volume such that the effective float will be 59 percent of the original float volume. When the float is pressurized to 3.5 psig, pressure in the second compartment will drop to 0.72 psig as a result of the increase in volume as follows:

Original Float Volume	140 ft^3	(241920 $in.^3$)
Original Float Pressure	3.5 psig	(18.2 psia)
One Cell Inflated Volume	82.6 ft^3	(142733 $in.^3$)

$$P_1V_1 = P_2V_2$$

$$(18.2 \text{ psia}) \left(\frac{241920}{2}\right) = P_2(142733)$$

$$P_2 = .72 \text{ psig}$$

This pressure is sufficient to maintain full buoyancy.

Several end configurations were proposed for the float, a flat end, a hemisphere and a combination of both. The flat end configuration provides the greatest volume for the given length and diameter. Hemispherical ends provide the least volume for the given dimensions. Flat ends cause scalloping at the seam where the ends are bonded to a cylinder. Fabric gussets were to be attached at this joint for carrying aircraft loads from the aircraft frame into the float but there was concern that the scalloping would effect the load path. Three one quarter scale floats were made of each type and configuration to demonstrate the problems and to determine volume differences. From these models the compromise configuration was selected. A full scale mockup float was fabricated using 8 gores in the end cap between the cylinder and the flat end (Figure 11).

Standard MS20760D8 fittings are used for inflation ports in each cell and are mounted inside the aircraft structure attached through nut plates inside the float for both forward and aft cells. The float is attached to the aircraft by 2 girth strips running the length of the float approximately 21 inches apart. These strips are bolted along existing aircraft stringers with aluminum angle retainers. Cord, bonded in the edge of the girth strip, prevents the strip from pulling out from under the retaining angle.

The load paths from the float to the aircraft was to be concentrated at 4 aircraft frames, stations 160, 190, 220 and 254. However, it was found to be impractical to design the float to carry the high loads concentrated at only 4 points. The load had to be distributed along the entire length of the float. Structure had to be added to the aircraft to carry the loads from the float to the 4 aircraft frames. It was determined that a 3 inch deep channel was needed to carry the load and external mounting of the channel would be the least costly

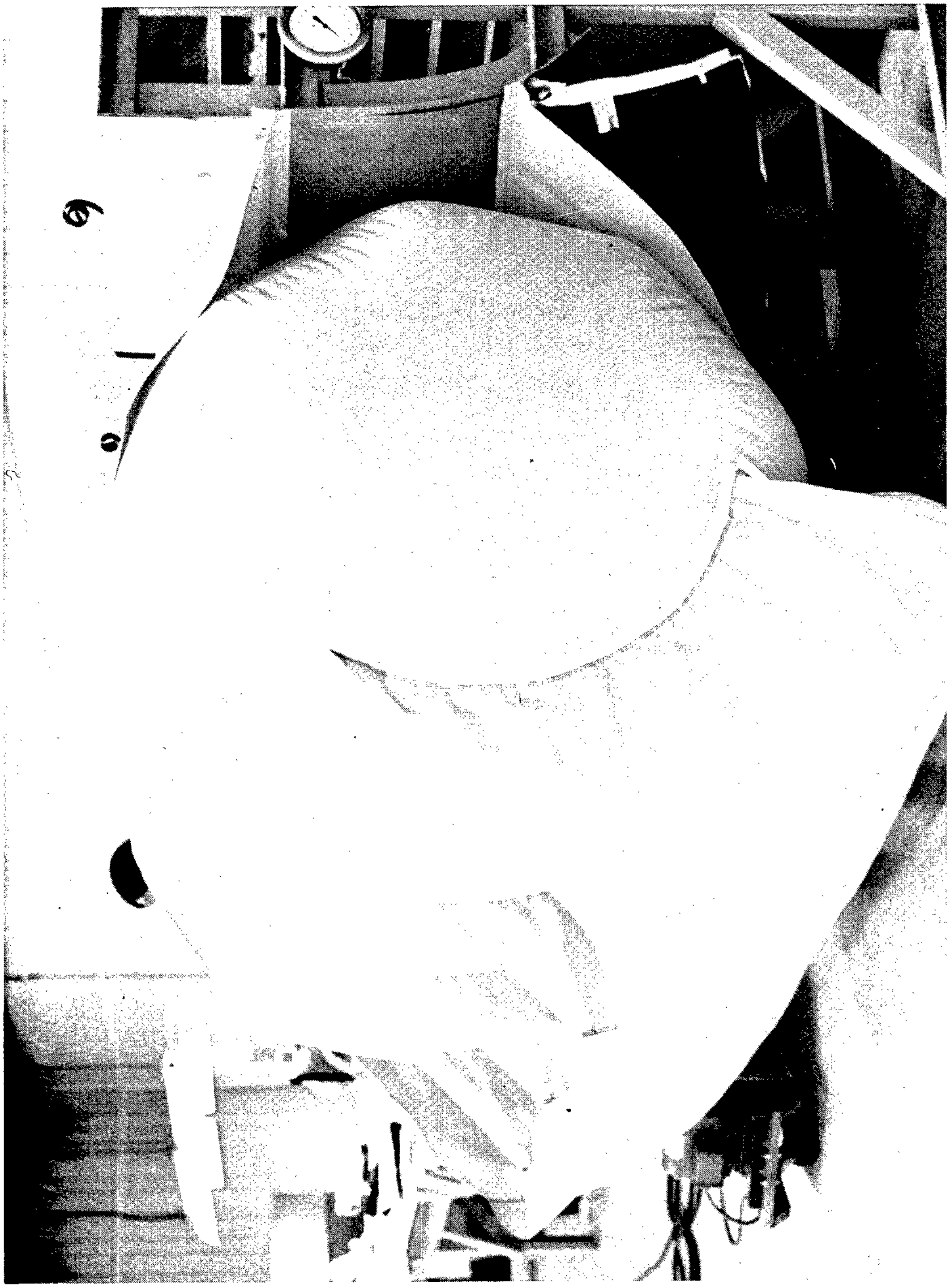


Figure 11. Mockup float showing 8 gore end cap.

regarding aircraft modification. A 3 inch channel was required at the bottom girth attachment while a 2 inch channel was required at the top attachment. These channels would also serve as retainers to prevent the beaded edge of the girth from pulling through. Loads for the girth attachments were determined assuming the full envelope of the H-46 operating manual water landing impact with the floats deployed. Descent rates used are 480 ft per second vertically and 20 knots forward or 240 ft per second and 30 knots forward. The maximum loads at each frame attachment point is shown in Figure 12.

Water Scoops

Attached to the outboard side of each float are pockets or scoops made of Kevlar fabric and lightly coated with polyurathane to provide water tight compartments. Scoops are divided into 4 compartments. The fabric is sufficiently stiff so that the scoops extend from the float so that sea water will freely flow in to fill the scoops. The top of the open scoops are located just below the waterline to permit water entry. During the inflation process the scoops are well below the water and as the float fills water is scooped up. Inflation of floats prior to water entry should present no problem to filling the scoops with water as the floats will be submerged during impact and the scoops will fill with water.

Float Pod

To stow the float in a folded condition on the side of the aircraft, a fiberglass pod was designed. The pod is 23 inches high by 100 inches long and the depth is 3 inches, which follows the aircraft contour. An aluminum hinge is provided at the bottom with a stainless steel hinge pin. The hinge at the top is of aluminum with an aluminum hinge pin. The pin is designed to shear at 136 pounds. Loops in the hinge are in 4 inch widths

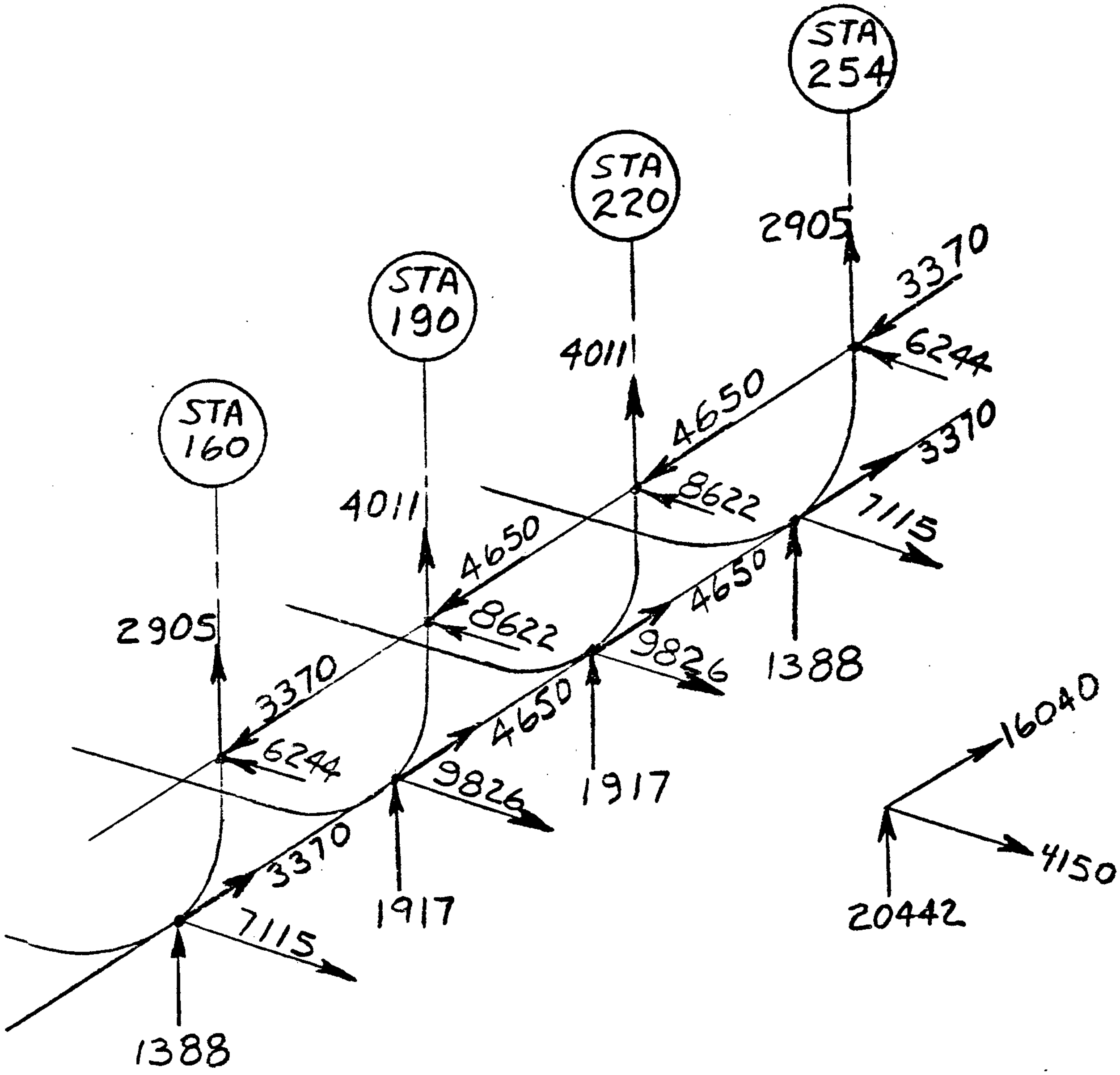


Figure 12. Aircraft Load Diagram For Float Input Loads.

so that the total shear load on the hinge is 34 pounds per inch. Hoop loading produced when the float is inflated to 3 psig will produce 34 pounds per inch load.

$$T = \frac{23 \text{ (Pod Hight)} \times 3 \text{ PSIG}}{2} = 34 \text{ lb/in.}$$

As the pin in the upper hinge shears, the pod cover swings down and the float inflates.

Pressurization Systems

Two types of pressurization systems were designed, one a direct blow-down system and the other an aspirated system. Each system has its advantages and disadvantages. The direct system requires 4 pressure cylinders of approximately 775 cu. in. with a weight of 82 pounds, assuming the use of LAMPS S-Glass cylinders. This weight does not include the extra wiring and brackets for installation. The aspirated system requires only one pressure cylinder but requires an aspirator at each float cell. The 4 aspirators, ducting and single pressure cylinder weigh 35 pounds.

Both systems present a space problem in a helicopter where space is limited. Space is available under the floor for installing the cylinders of the direct system, however, this location is undesirable from a servicing and inspection standpoint. Check of cylinder pressure is required prior to each over water flight and floor removal for this check is impractical. Installation of inspection hatches would be costly and would weaken the floor. Aspirators for the aspirated system must be located close to the float inflation ports. This location would encroach on the troop seat area. Another problem with the aspirated system is the possibility of water injestion if the aircraft begins taking on water after water impact. A standpipe is needed to raise the air intake port sufficiently high to avoid in-rushing water. Availability of sufficient cabin air must also be considered. Approximately 260 cu. ft. of air is needed to be pumped into the floats in approximately 7 to 10 seconds. With all hatches closed, air must enter through openings in the pylon areas. Openings in the pylon areas should be sufficient to permit outside air to enter without choking aspirators. Testing the aspirated system in a full scale aircraft should be performed to assure that pylon openings are large enough to supply sufficient air to the aspirators. A trade-off will have to be made to determine if the weight saving and other advantages of the aspirated system are more than the disadvantages.

Aircraft Structural Provisions

All aircraft loads would be transferred to the floats through 4 frames, at stations 160, 190, 220 and 254. Hard point fittings were designed for attachment of the upper and lower girth members on both sides of the aircraft at each frame. A typical frame modification for attachment is shown in Figure 13. Stress analysis of the frames indicated that reinforcement of the 4 frames was also necessary (Figure 14). Cap angles are needed in the crown area and along the lower sides. A total of 6 pounds of material is required to be added for the frame reinforcement and 6.2 pounds for hard point fittings. Available frame area and required frame area is tabulated in Table 3. External channels required to distribute the aircraft load to the float and described under float design, would weigh approximately 21.6 pounds for a total structures weight of 33.7 pounds per aircraft. Channel installation is shown on the test fixture installation (Figure 15).

Test Fixture

A test fixture was designed and fabricated. The fixture represents a section of the CH-46 aircraft from sta 160 to 254 and the height from waterline -30 to +9. Actual frame sizes and

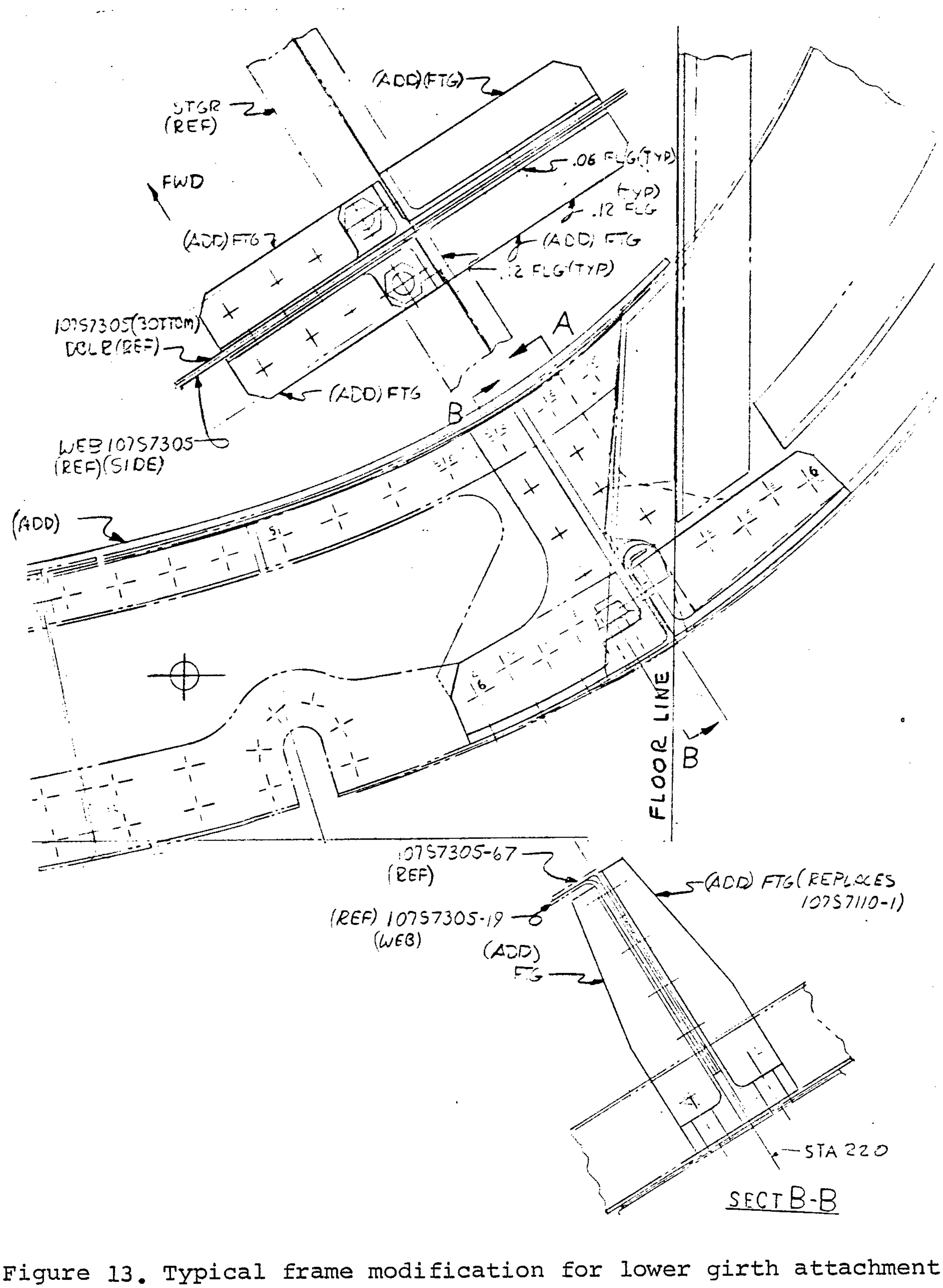


Figure 13. Typical frame modification for lower girth attachment.

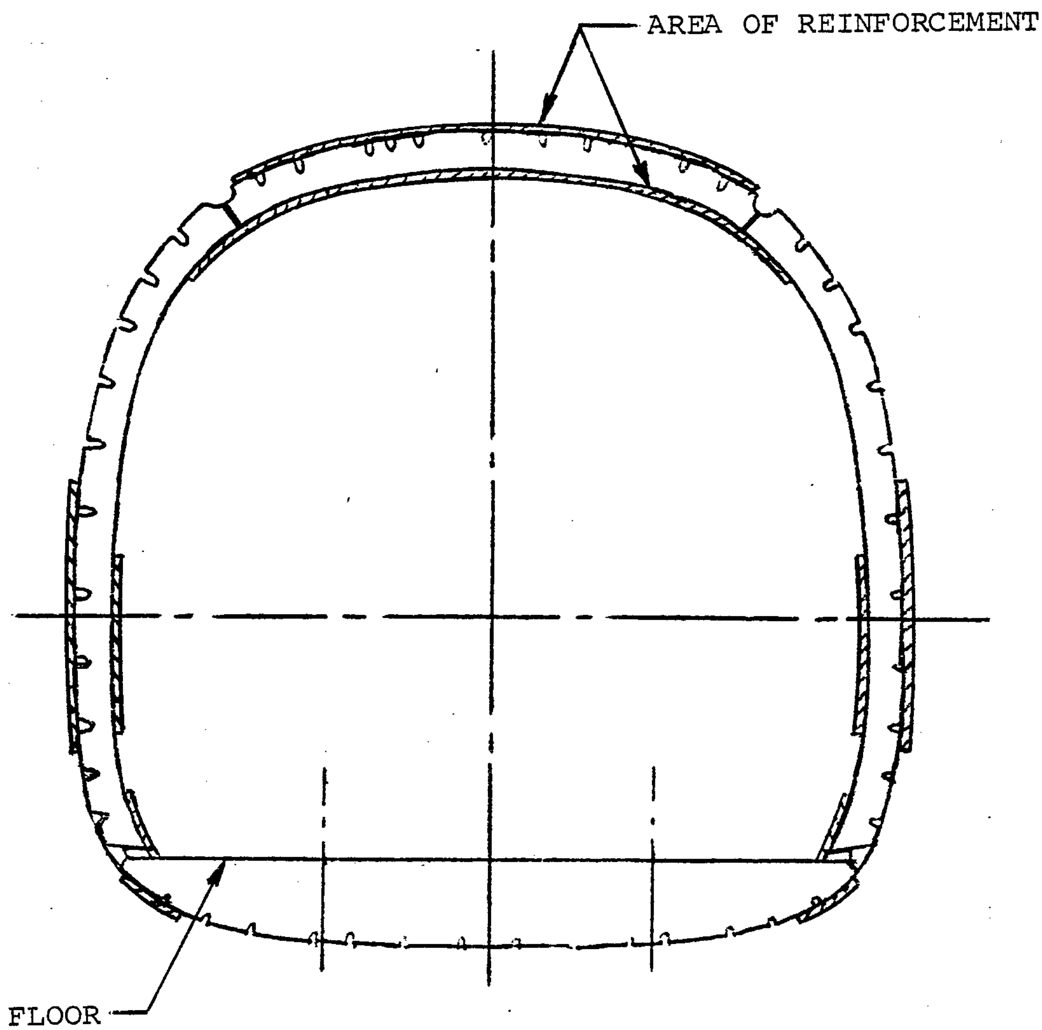


Figure 14. Typical frame reinforcement.

TABLE 3 - ADDED WEIGHT FOR FRAME REINFORCEMENT					
STA	LOCATION	AVAILABLE AREA-IN^2	REQUIRED AREA-IN^2	ADDED AREA-IN^2	ADDED WEIGHT-LB
160	RH INSIDE	.390	.156	-	
	RH OUTSIDE	.468	.321	-	
	RH BOTTOM INSIDE	.421	.342	-	
	RH BOTTOM OUTSIDE	.398	.181	-	
	LH INSIDE	.390	.156	-	
	LH OUTSIDE	.468	.321	-	
	LH BOTTOM INSIDE	.421	.342	-	
	LH BOTTOM OUTSIDE	.398	.181	-	
	TOP INSIDE	.339	.155	-	
190	RH INSIDE	.405	.156	-	
	RH OUTSIDE	.329	.321	-	
	RH BOTTOM INSIDE	.480	.342	-	
	RH BOTTOM OUTSIDE	.094	.181	.087	.090
	LH INSIDE	.104	.156	.052	.100
	LH OUTSIDE	.108	.321	.213	.560
	LH BOTTOM INSIDE	.252	.342	.090	.120
	LH BOTTOM OUTSIDE	.054	.181	.127	.130
	TOP INSIDE	.057	.155	.098	.732
220	RH INSIDE	.628	.156	-	
	RH OUTSIDE	.450	.321	-	
	RH BOTTOM INSIDE	.334	.342	-	
	RH BOTTOM OUTSIDE	.094	.181	.087	.090
	LH INSIDE	.104	.156	.052	.100
	LH OUTSIDE	.108	.321	.213	.560
	LH BOTTOM INSIDE	.252	.342	.090	.120
	LH BOTTOM OUTSIDE	.054	.181	.127	.130
	TOP INSIDE	.057	.155	.098	.732
254	RH INSIDE	.104	.156	.052	.100
	RH OUTSIDE	.108	.321	.213	.560
	RH BOTTOM INSIDE	.252	.342	.090	.120
	RH BOTTOM OUTSIDE	.054	.181	.127	.130
	LH INSIDE	.104	.156	.052	.100
	LH OUTSIDE	.108	.321	.213	.560
	LH BOTTOM INSIDE	.252	.342	.090	.120
	LH BOTTOM OUTSIDE	.054	.181	.127	.130
	TOP INSIDE	.057	.155	.098	.732

STRAPS	5.94 LB
FITTINGS	6.20 LB
EXTERNAL CHANNELS	21.6 LB
TOTAL	33.74 LB

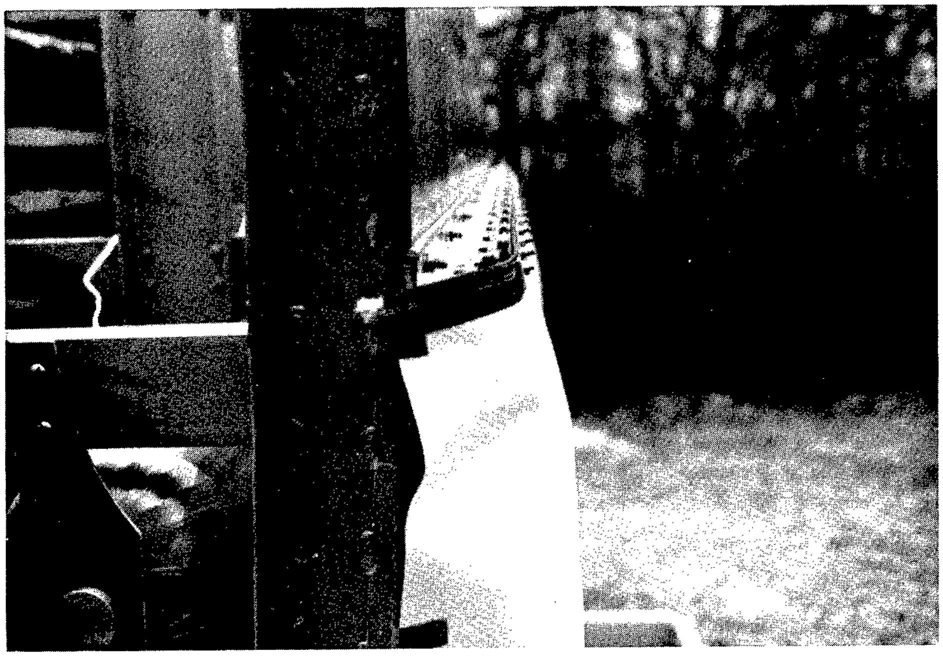


Figure 15. External structure reinforcing channel.

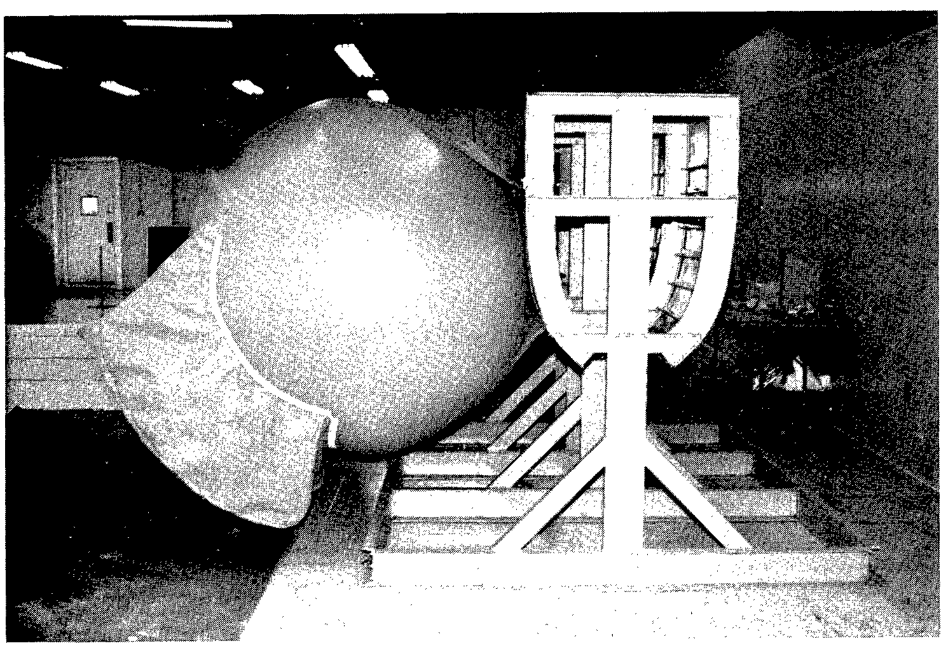


Figure 16. Steel test fixture.

stringers were represented. However, steel was substituted for aluminum. Steel was used for ease of fabrication by welding and also to provide the strength to withstand static tests to be performed during the follow-on program. The steel frame was covered with the actual thickness of aluminum material as used on the aircraft. Both sides of the aircraft were represented. However, the distance between sides was shortened to conserve space. A structural steel base was used to support the test fixture (Figure 16).

TEST PROGRAM

Test Plan

A test plan was prepared and is reproduced in Appendix A. The test plan covers the complete system demonstration for the direct blowdown system and for the aspirated system. However, prior to complete system demonstrations a number of pressurization tests were conducted on a mockup float.

Mockup Float

A mockup float was fabricated to check float size and volume, general pattern accuracy and installation interface problems. The mockup float was installed on the test fixture by attaching the upper and lower girth strip members. The strips were retained by a cord sewn in the edge of the strip and then clamped to the test fixture by an aluminum angle 1 inch by 1/2 inch and 8 feet long. Inlet ports inside the test fixture were interfaced with nut plates inside the float, one port for each of the 2 cells.

Mockup Float Test

The float was inflated with shop air and at a pressure of 0.5 psig the float was firm. A 140 pound person climbed onto the float and was supported with no observable indentation (Figure 17). A dimensional check was made and it was found to be 95.5 inches, short by 4.5 inches. The diameter was 60 inches which was 2 inches more than the required 58 inches. Volume was checked by using a flow meter during inflation and timing the flow, volume was found to be 133 ft^3 or 7 ft^3 under the required 140 ft^3. Volume was checked in a similar manner during inflation of a single cell and was found to be 78.7 ft^3 (Figure 18). Inspection of the float at the 0.5 psig pressure showed a straining of the fabric at the inlet ports. The curvature of the float ends was greater than anticipated, placing the ports into the curved area. Higher pressure with this condition was feared so a modification was made. The inlet port was removed from the inner surface of the test fixture and mounted directly on the float. A hole was cut in the test fixture to allow the inlet port to float free. Pressure was increased to 3.5 psig, the maximum operating pressure. A dimensional check was made at this pressure and the dimensions remained essentially the same due to the low elongation of the Kevlar material. Leakage was checked and found to be less than 200 SCCM.

Burst Pressure Test

Pressure in the float was increased to determine the burst pressure. A pressure of 7.3 psig was reached when the float burst. The fabric was torn from one end of the float to the other (Figure 19). The girth strip retaining angle was damaged (Figure 20). The center bulkhead also split across its diameter. Failure originated at a point where the girth strip ended abruptly on the surface of the float. No reinforcement was used at this point. Higher burst pressure is anticipated with improved girth termination and reinforcements. Note however, that the draft specification to the vendor required 6 psig minimum burst pressure.

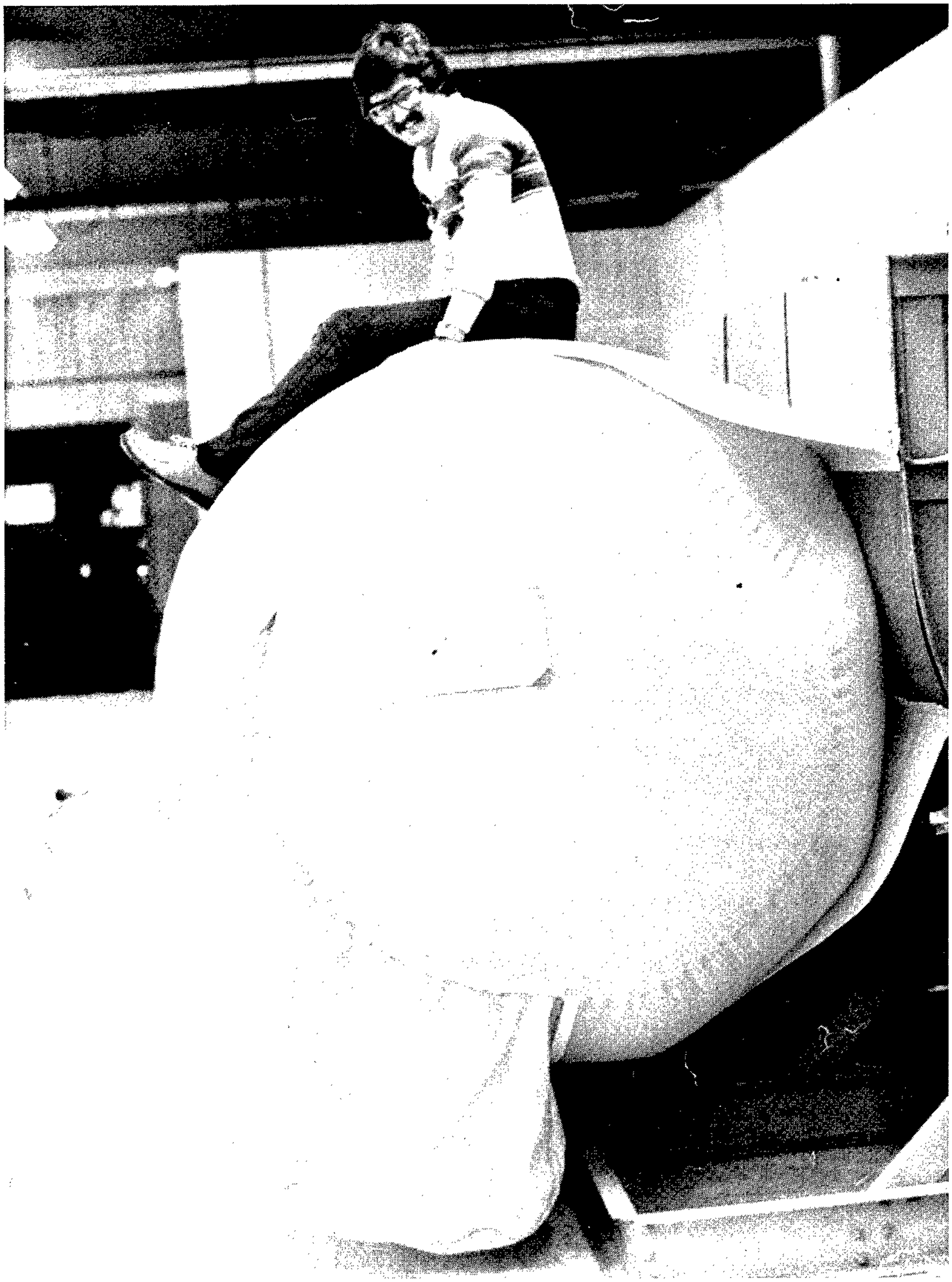


Figure 17. Firmness of float at 0.5 psig demonstrated.

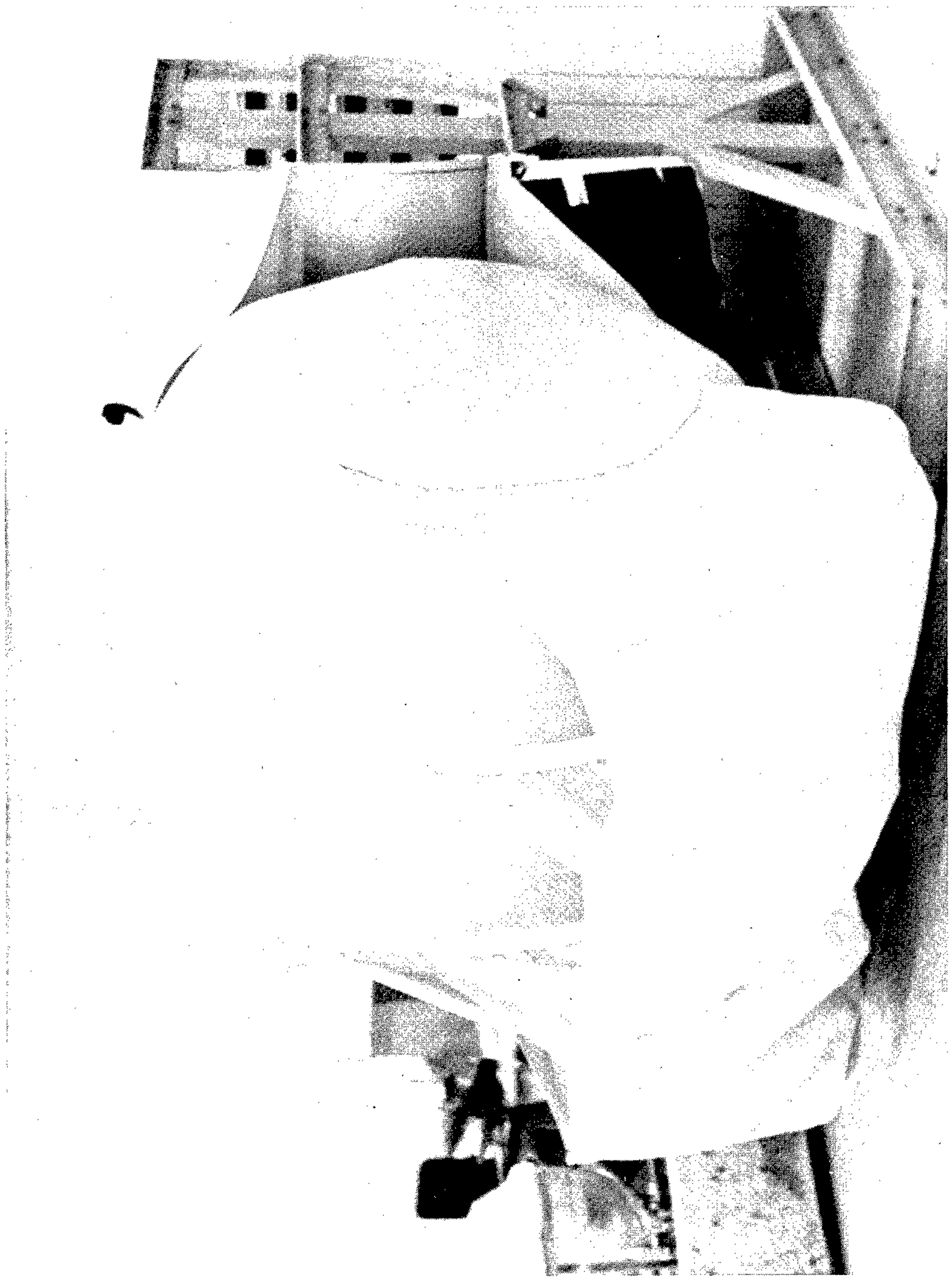


Figure 18. Float with one cell inflated.

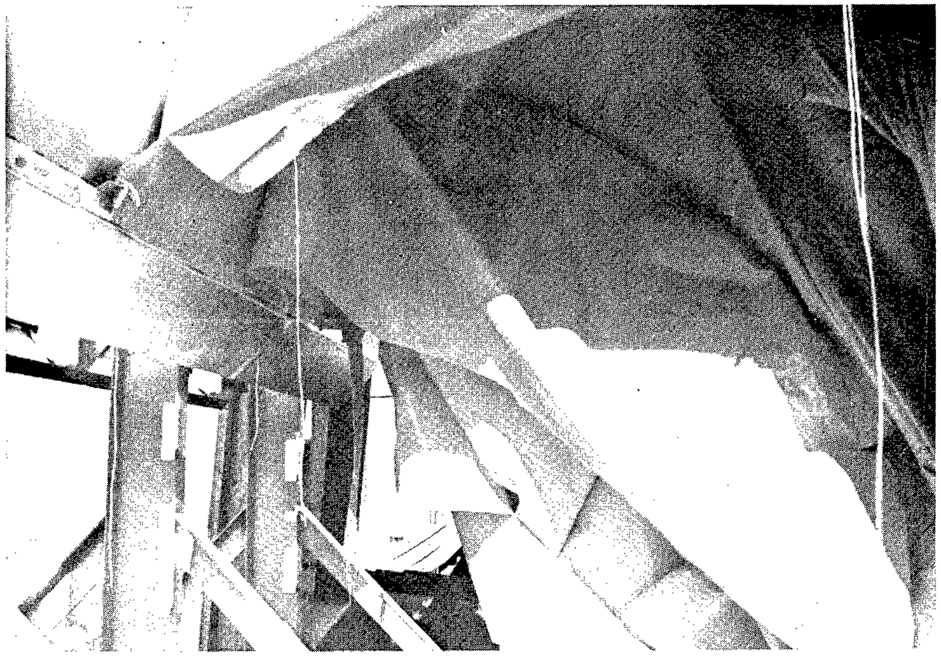


Figure 19. Float after burst test.

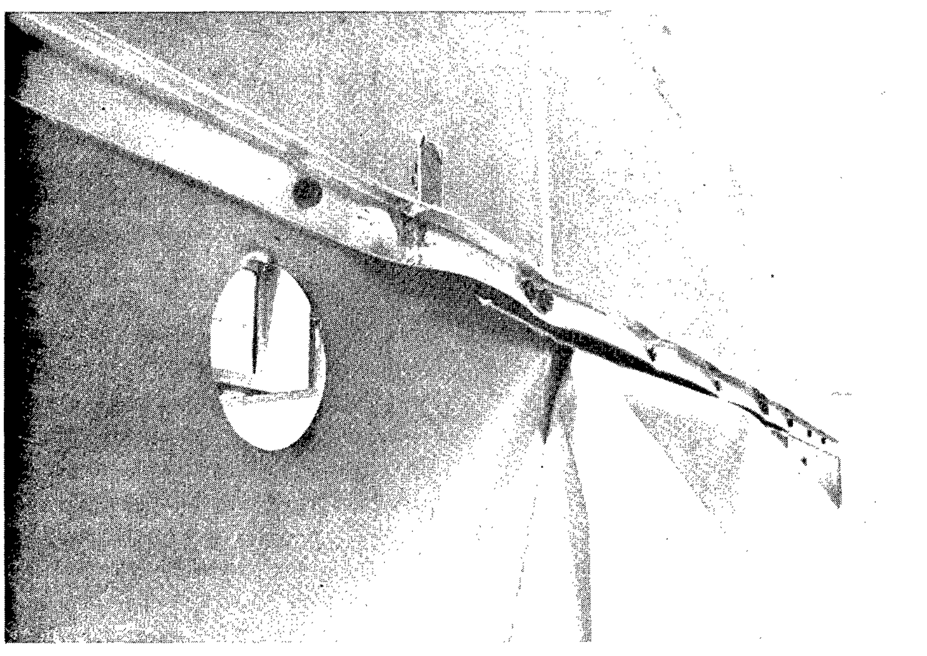


Figure 20. Distorted girth strip retaining angle.

Prototype Float Test

A second float was fabricated and was designated the prototype float. Changes found to be necessary in the mockup float were incorporated in the prototype float. These included dimensional changes, inlet port locations, increase of girth strip width and doubling the number of end cap gores to 16. The girth strip width was increased so that the float would set farther away from the side of the fuselage (Figure 21). This would relieve the high static load on the girth strips due to the pressure of the float pushing against the side of the fuselage when it is inflated. End cap gores were increased to provide a smoother surface. The float was pressurized to 3.5 psig and leak checked. Volume was measured and found to be 136 ft^3.

Pneumatic System Test Preparation

The system was designed for a separate Nitrogen cylinder to pressurize each cell of the float. Each cylinder has a capacity of 782 cu. in. when pressurized. Pressure in the cylinders was determined as follows:

$$P_1V_1 = P_2V_2$$

$$P1 = \frac{(3.5\ psig)\left(\frac{136 ft3}{2}\right)}{782\ in^3} = \frac{(18.2\ psia)(117504\ in^3)}{782\ in^3}$$

$$P_1 = 2720\ psig$$

Each cylinder was charged to 2720 psig at room temperature, 68 degrees. The cylinders were clamped into the cradles and brackets provided in the test fixture (Figure 22). A one half inch stainless steel line was connected from each cylinder valve to the inlet port in the test fixture (Figure 23). Electrically fired squibs, in the cylinder valves, were wired through a water pressure sensing switch to a 28 volt power supply.

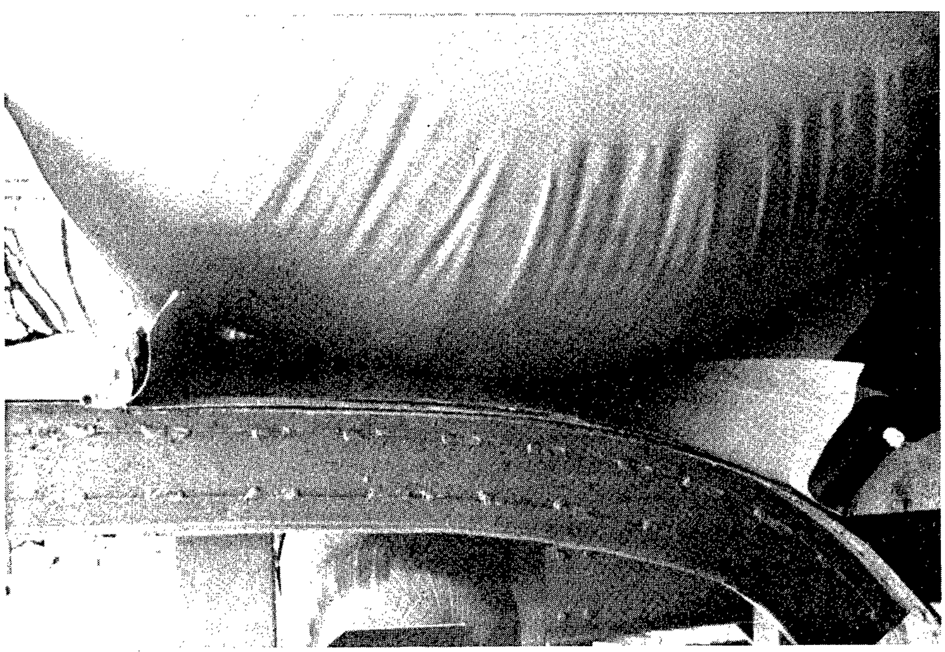


Figure 21. Prototype float with extended girth strips.

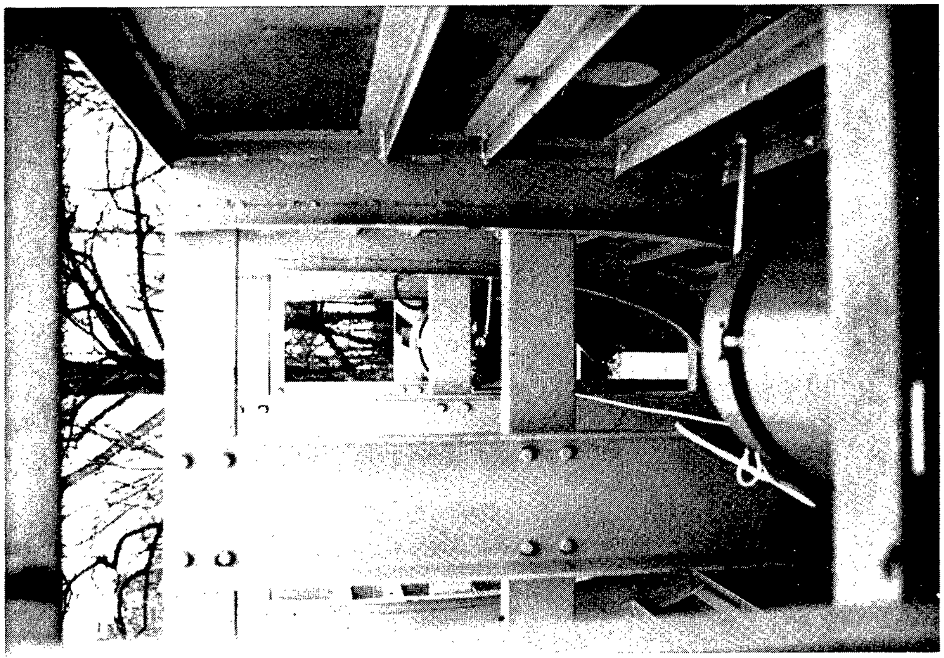


Figure 22. Nitrogen cylinders installed in test fixture.

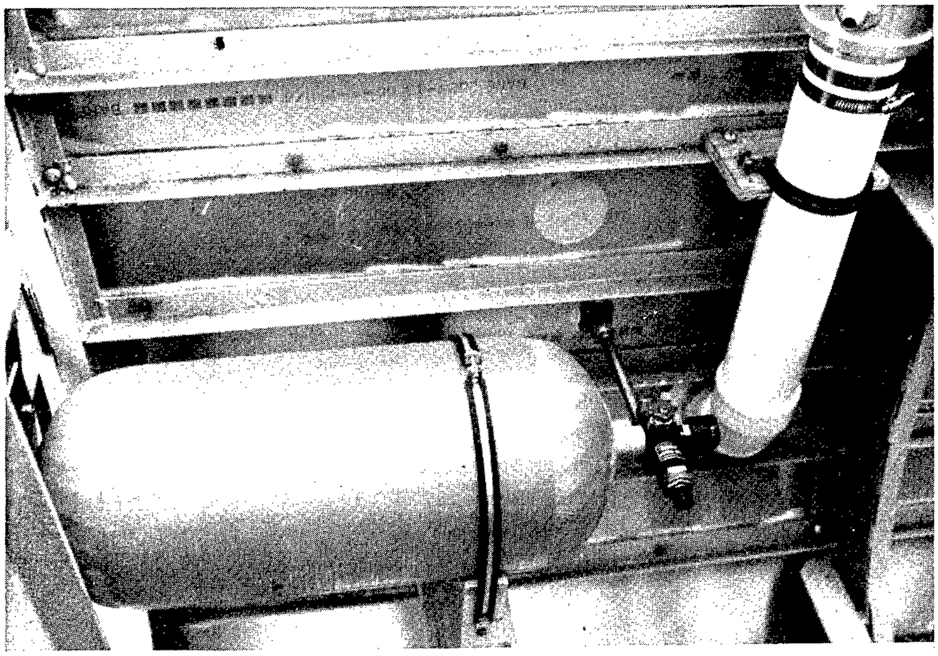


Figure 23. Plumbing from cylinder to inlet port.

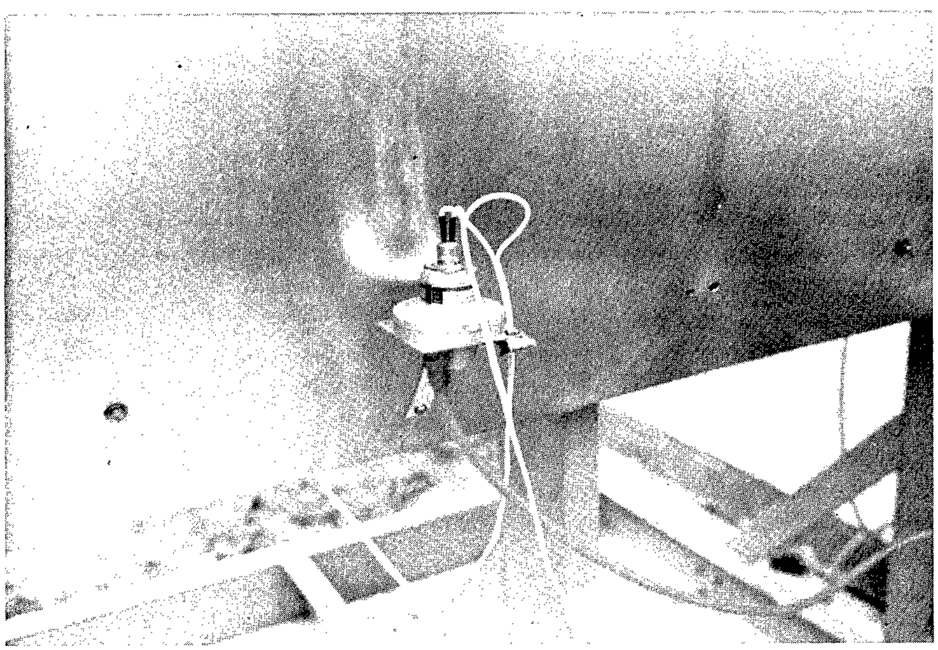


Figure 24. Water pressure sensing switch installation.

Water Pressure Sensing Switch

The water sensing switch (Figure 24) was installed on the outside of the test fixture. A plastic hose was connected at one end to the sensor and the other end was inserted into a container into which water could be added. Note that ITT Neo-Dyn provided the switch on loan for test purposes.

Pre-Test Float Installation

The float was installed on the test fixture, attached by a 2 inch channel at the upper girth and a 3 inch channel at the lower girth. The float was rolled in 3 flat folds against the side of the test fixture and was contained by a heavy polyurathane coated fabric pod cover. The bottom edge was fastened to the lower channel and the upper edge to the frangible hinge. Measurement of the pod showed that the 3 inch depth limitation was not exceeded. The volume objective for the packed float is 2 ft^3.

System Demonstration - Test 1

The system configuration to be demonstrated consisted of a direct blow-down nitrogen system with automatic initiation triggered by a water sensing switch. Nitrogen cylinders were tied directly to each float cell by a 0.50 diameter stainless steel line.

Both nitrogen cylinders had been charged to approximately 2700 psig at 68 degrees room temperature. The test was to be conducted outside and the test fixture was moved outside the night before the test. Temperature during the night dropped to 32 degrees, cold soaking the nitrogen. At the time of the test the air temperature stood at 35 degrees with the nitrogen temperature at approximately 32 degrees. At this temperature the pressure in the cylinders had dropped from 2700 to approximately 2500 psig.

Instrumentation consisted of a Sanborn recording device (Figure 25) which traces float pressure variations on a strip chart. A 35mm camera, with automatic rewind, was set up to record the inflation sequence.

The system was initiated by allowing water to flow into a container with sensor hose inserted (Figure 26). When the water level reached 13.5 inches on the hose, the sensor switch closed applying power to the system. The squibs fired, driving a cutter through the pressure disk, allowing the nitrogen to flow into the float. Instantaneously, the pod frangible hinge pin sheared due to pressure in the float. The pod cover opened and the inflation sequence is shown in Figure 27. The pod cover hung down from the lower girth attachment (Figure 28). Full formation of the float occurred, however, a low pressure was recorded. Upon close examination of the float, two holes, approximately one inch in diameter, were found in the float opposite the two inflation ports. The force of the entering gas against the folded float had caused the polyurathane coating to lift off of the Kevlar fabric.

Inspection of the system showed that the frangible hinge pin functioned properly, shearing at each loop and without hinge deformation (Figure 29). The nitrogen inflation system withstood the thrust forces without displacing the cylinders or loosening the plumbing connections. At disassembly of the cylinder firing mechanism, both the primary and redundant elements in each squib were found to have fired.

Review of the instrumentation strip chart showed that pressure in the float did not increase sufficiently to determine inflation time. This was a result of the large leaks. Examination of the photographs showed that full formation of the float occurred on the thirteenth picture after initiation (Figure 27). This would indicate that it required 13 seconds for full forming

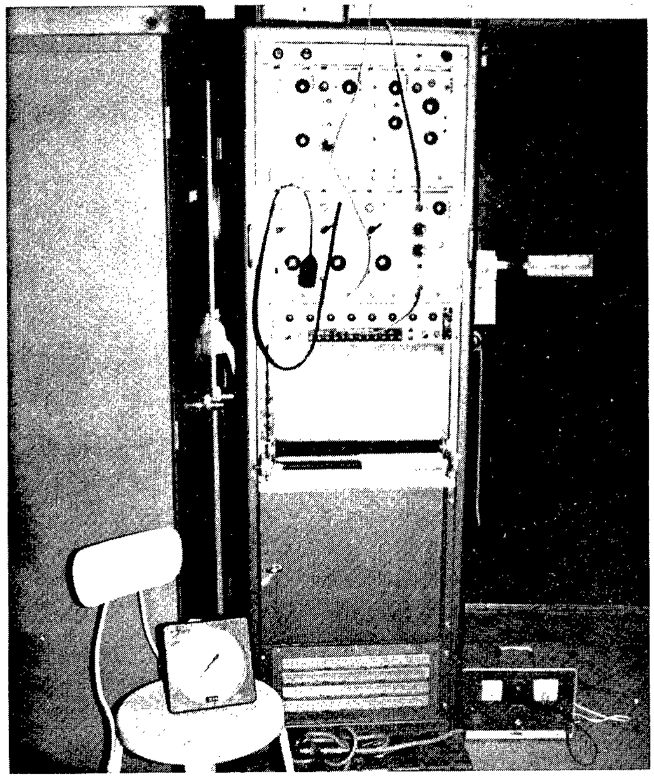


Figure 25. Sanborn strip chart float pressure recorder.

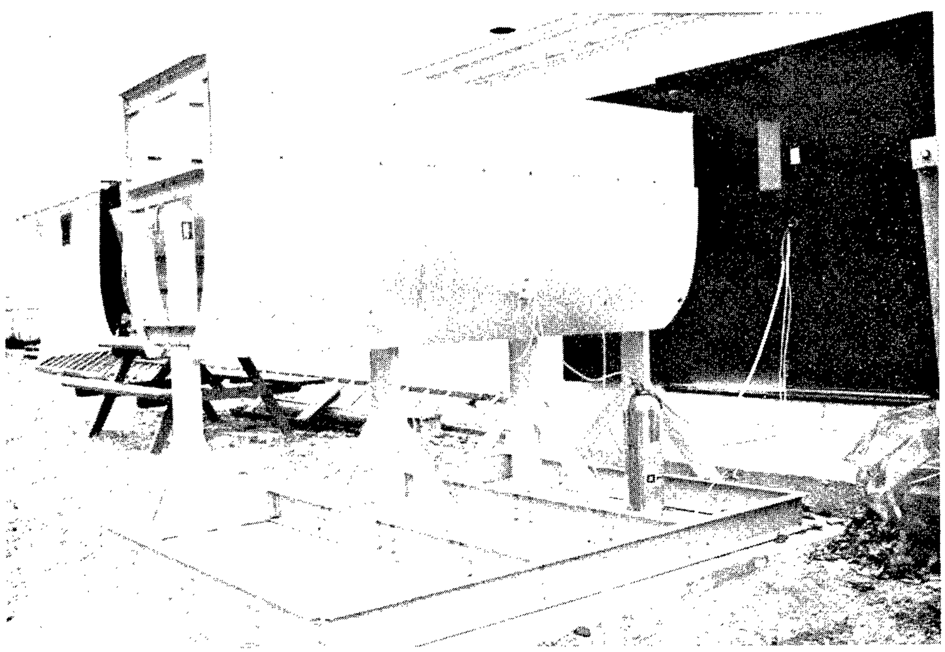


Figure 26. Container for water sensor hose.

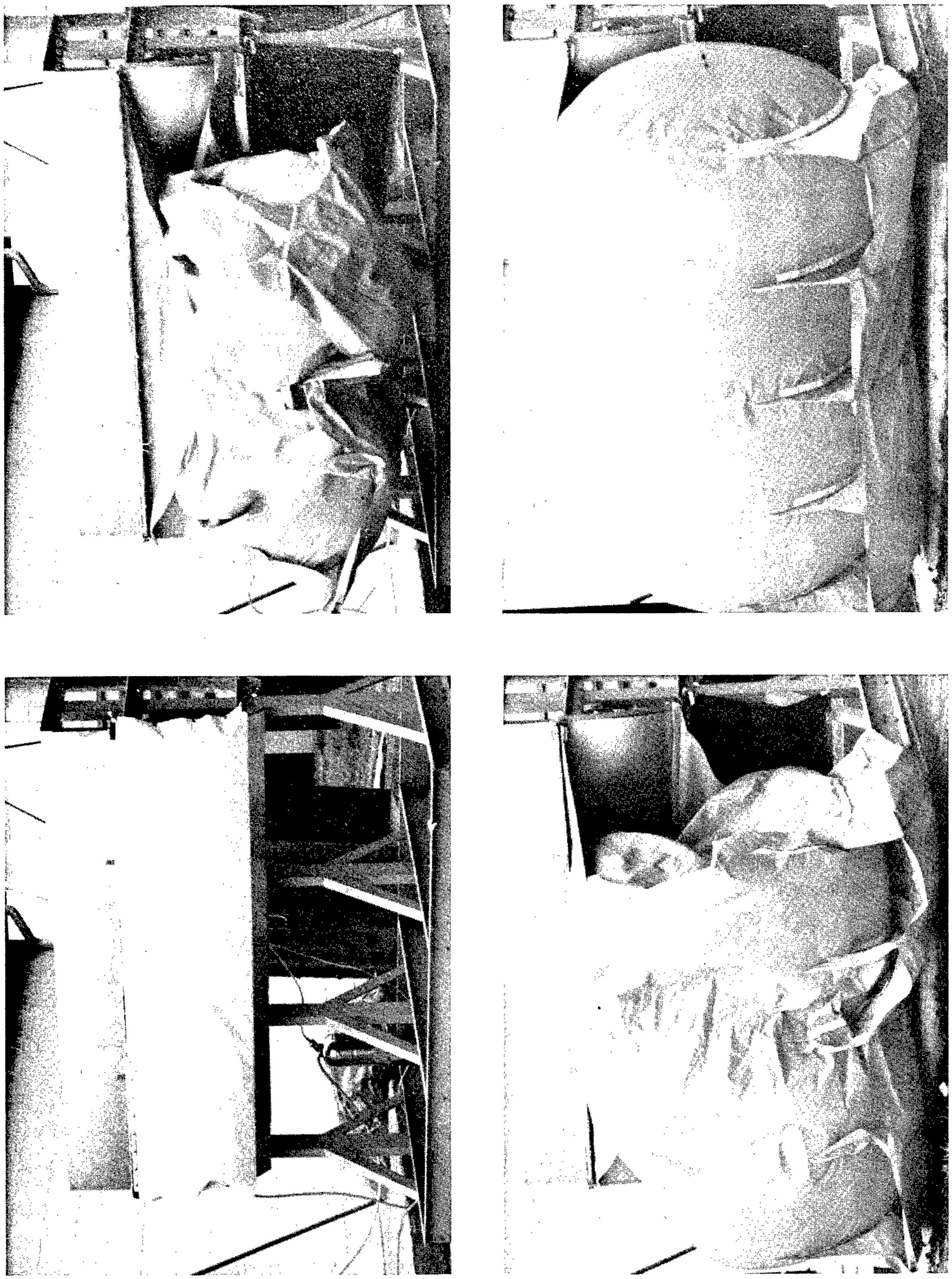


Figure 27. Prototype float inflation sequence.

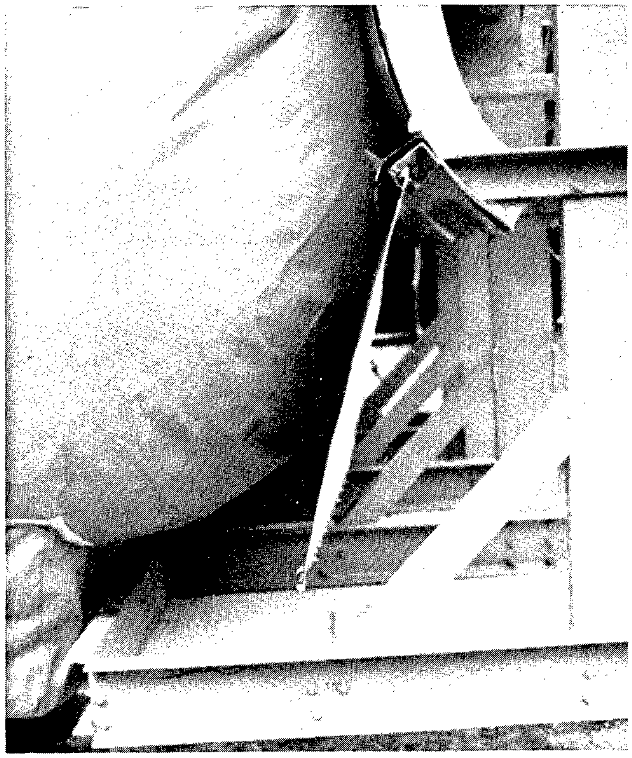


Figure 28. Opened pod cover hanging from girth attachment.

Figure 29. Frangible hinge after opening operation.

of the float, as the photographs were taken at one per second. Additional time would have been required to increase float pressure to full operational pressure.

<u>System Demonstration - Test 2</u>

The system configuration to be tested consisted of a direct blowdown nitrogen system with semi-automatic initiation. This initiation system bypasses the water sensor and is initiated by a switch which can be activated by the pilot when the system is armed. Nitrogen cylinders had been pressurized to 3000 psig and were quite hot due to the compression filling process. Pressure in the cylinders dropped to 2700 psig when they cooled to room temperature. Further cooling occurred when the test fixture was taken outside where the temperature was 38 degrees, pressure on both gages dropped to 2400 psi.

Instrumentation consisted of the Sanborn strip chart recorder for float pressure and a high speed movie camera set for 300 frames per second. When the initiation switch was thrown, only one nitrogen cylinder fired. In spite of only one float cell inflating, the frangible hinge separated its full length and fell down out of the way as the cell inflated. The electrical system was checked and a loose connection was found. When the connection was tightened, the second cylinder was fired successfully and the full float was formed (Figures 30 and 31). Initial pressure in the float was recorded at 0.2 psig. Pressure increased to 0.75 psig in 30 seconds as the gas in the float warmed up.

Inspection of the system after the test showed that the float had developed a slight leak at a point where the girth strip meets the tangent point of the end cap and bonding of the two

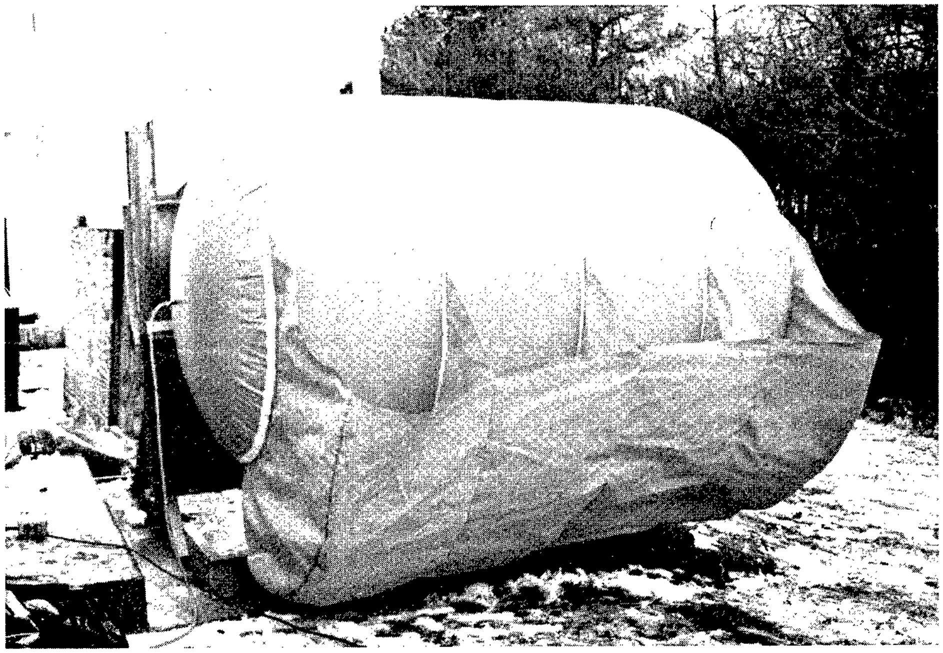


Figure 30. Test 2 inflated float showing instrumentation line.

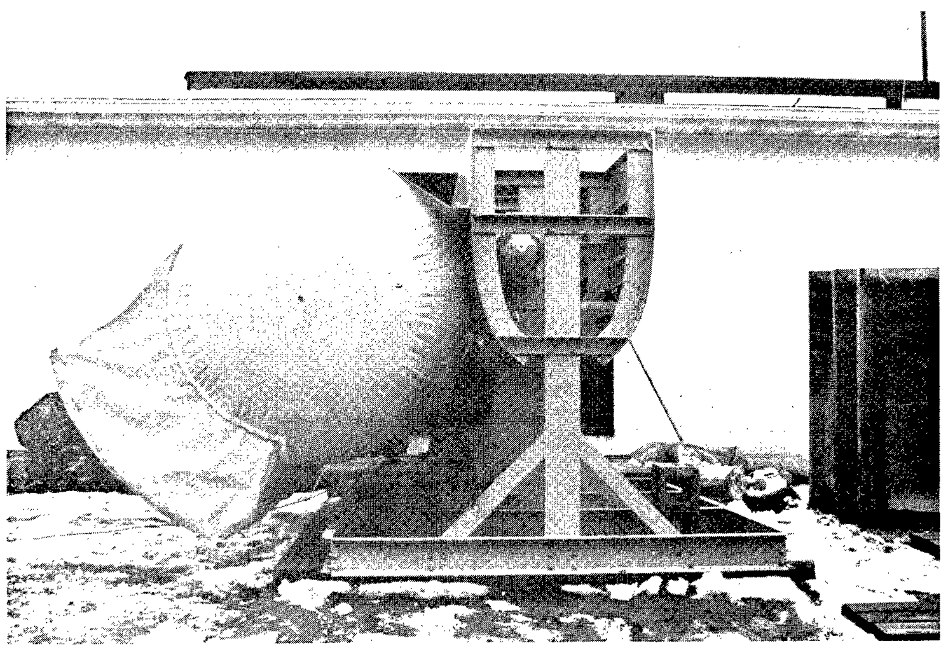


Figure 31. Test 2 inflated float at 0.75 psig.

stops. A slight deformation of the frangible hinge loops was found in the area where the second cell failed to inflate but presents no problem. Deformation was due to the angular load applied by the force on the pod cover by inflation of the number one cell. No other system discrepancies were found.

System Demonstration - Test 3

Due to the problems encountered on the first two demonstrations of float inflation with the direct blow-down nitrogen system, the contractor was directed to defer demonstration of the aspirated system and to repeat test No. 2. Installation of the aspirator is shown mounted on a standpipe with elbow inlet to the float at the bottom (Figure 32).

The nitrogen cylinders had been inflated to 3000 psig and 2750 psig when cooled to room temperature. The discrepancy in pressures was due to the cylinder pressurization process. Initially both cylinders were pressurized to 3250 psig, the limit of the compressor. The cylinders were quite hot and were allowed to cool. When cooled both cylinders were topped off to 3250 psig. However, when one was topped off considerable gas was lost due to a faulty fill hose connection and more heating occurred in topping it off after the leak had been stopped.

The float was evacuated with a vacuum pump, then folded and packed against the side of the test fixture in the fabric pod. A new aluminum frangible hinge pin was inserted. The nitrogen cylinders were installed when the temperature was 2 degrees above zero fahrenheit. At the time of the test, the temperature was 10 degrees f and pressure in the cylinders had decreased to 2750 and 2500 psig.

Instrumentation consisted of the Sanborn strip chart pressure recorder, a stop watch, a high speed movie camera set at 300

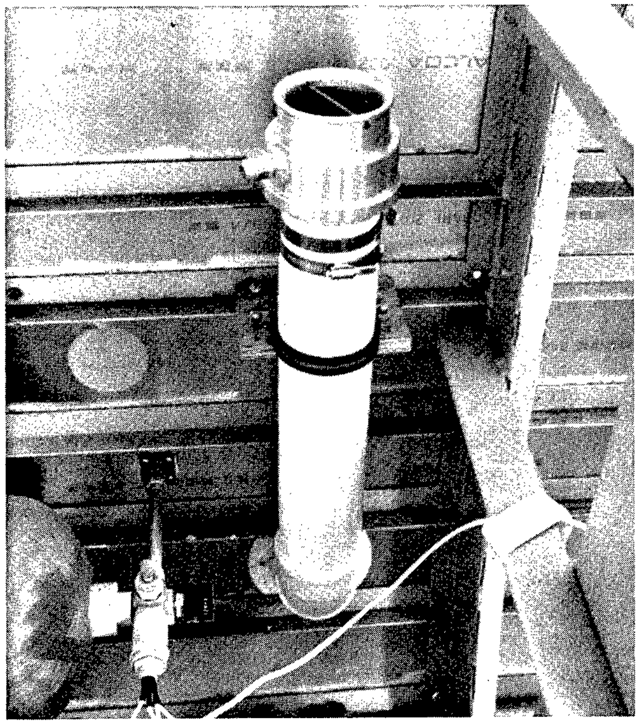


Figure 32. Aspirator inflation system installation.

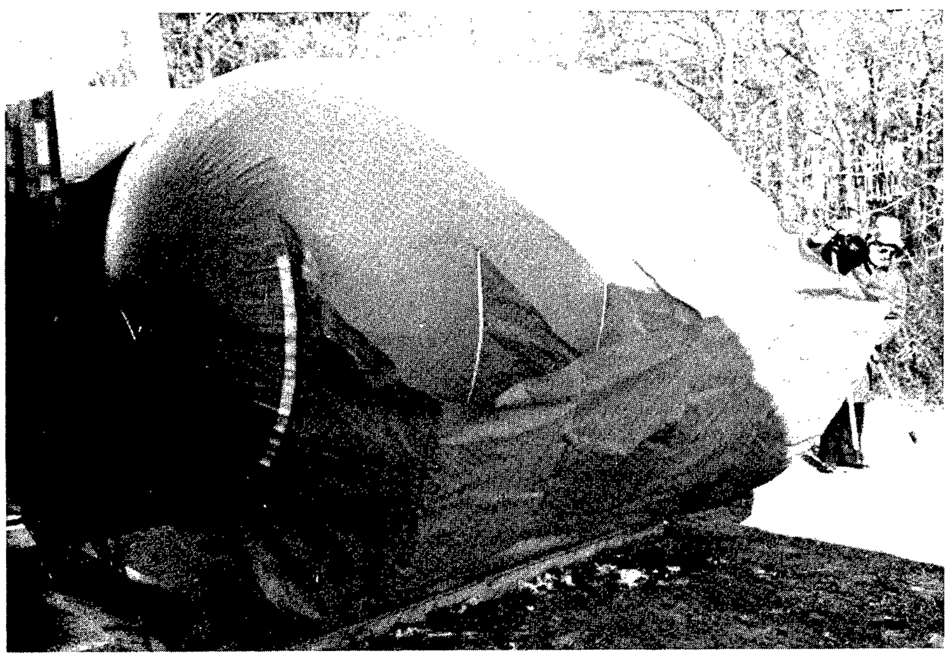


Figure 33. Test 3 inflated float at 1.2 psig.

frames per second and a real time speed movie camera at 24 frames per second. Recorder and cameras were started 3 seconds before system initiation. The initiation switch was thrown and both nitrogen cylinders fired. The pod instantly opened and the float inflated. Using a stop watch, float inflation was timed. It required 14 seconds for the float to be fully formed and 17 seconds for the cylinders to completely discharge (Figure 33). Float pressure at this time was 0.5 psig. Pressure slowly increased as the gas heated up. The gas is cooled as it expands at the inlet port orifice and frost coated valves and lines result (Figure 34). A pressure of 1.2 psig was reached in 180 seconds (Figure 35). Leaks in the float, which had not been repaired from the previous test, prevented the pressure from increasing.

Inspection of the system after the test showed that all components functioned properly. No deformation or damage to the frangible hinge, the pneumatic system or the float was observed.

Test Conclusions

All system components including the water sensor, pneumatic system, squibs, pod cover with frangible hinge and float proved to function properly. Several problems however remain. The inflation time is excessive. Several things could contribute to the 17 second inflation time which was more than double the established time limit. An off the shelf nitrogen cylinder valve having a pressure gage was used in the tests and has an outlet fitting for 3/8 in. tubing. The valve without a pressure gage, used on the LAMPS inflation system, has an outlet fitting for 1/2 in. tubing, but does not have a pressure gage. The hole size is 0.391 inch diameter on LAMPS compared to 0.297 inch diameter on the test valve. Area ratio is almost 2 to 1 which would account for most of the increase in inflation time. Use of a sock in the float at the inflation port, to attenuate the initial jet force against the folded float, could also increase inflation

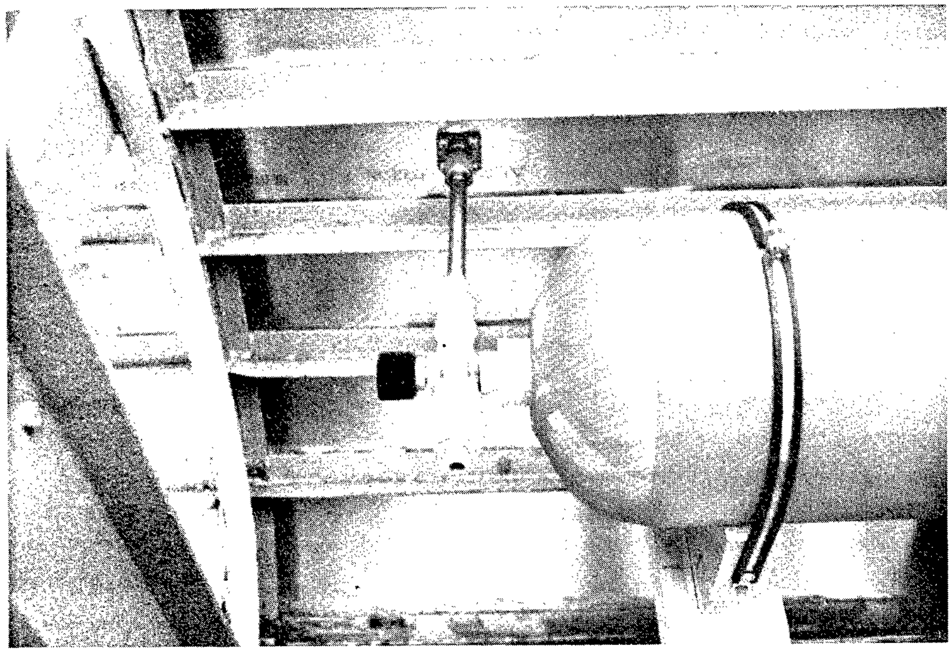


Figure 34. Expanding gas cools the lines causing frost to form.

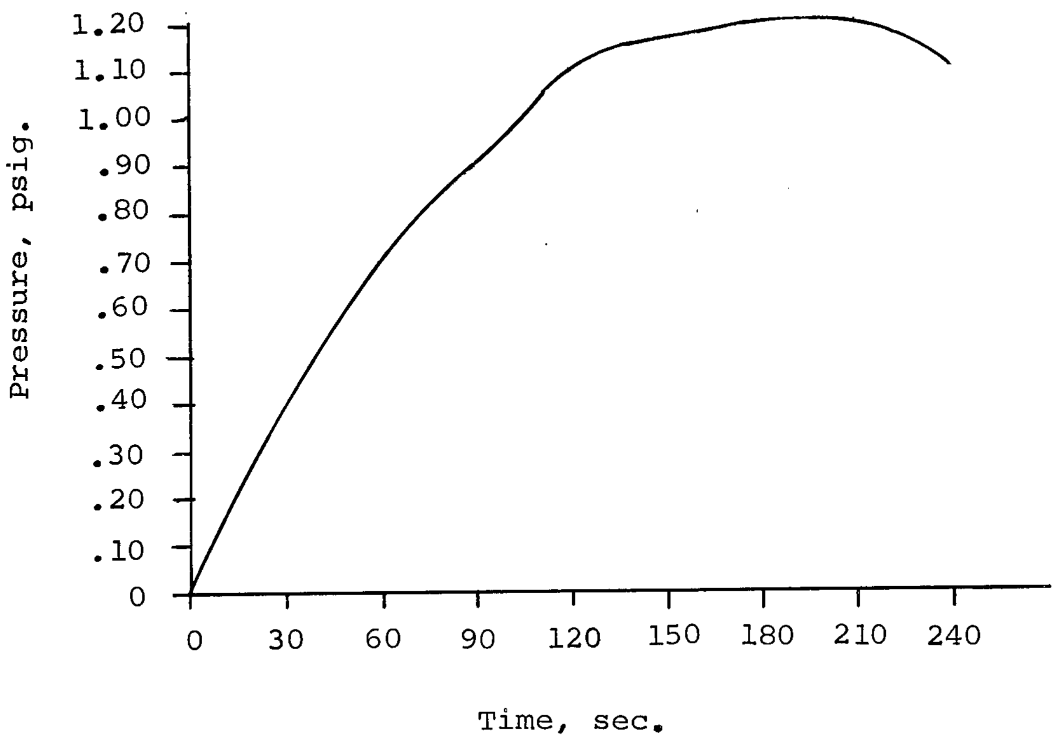


Figure 35. Float pressure vs. inflation time.

time. Use of nitrogen in the system also doubles the inflation time of a similar system using helium, as planned for LAMPS.

A serious problem inherent in all compressed gas systems is the cooling of the gas as it expands at the inlet port orifice. This problem is not present in an aspirated system due to the large inlet port. The cooled gas in the float requires approximately a minute to warm up and increase the float pressure to the desired level. Case histories show that helicopters have rolled over and sunk in 15 seconds, so the warm up time is excessive. One consideration which would resolve the problem is to inflate the float in the air before impact, allowing time for the gas to warm up. This would not accomodate those aircraft which inadvertantly enter the water without prior warning to the pilot. Hard landings may damage the auxiliary flotation system if the floats are deployed prior to impact. Another consideration is to provide an excess of gas in the cylinders and have a relief valve set at 2.5 to 3.5 psig. The problem with this is that if the floats are deployed before impact and a hard landing is made, pressure in the float would rise due to the impact, the relief valve would open and most of the gas would escape.

In addition to the problem of the gas cooling in the float, there is a problem of the reduction in gas pressure in the cylinders due to drop in ambient temperature. Table 3 shows the relationship of gas pressure in the cylinder and pressure in the float for a range of ambient temperatures.

TABLE 4 - FLOAT PRESSURE VS. AMBIENT TEMP				
CYLINDER PRESSURE PSIG	TEMPERATURE DEGREES FAHRENHEIT	CYLINDER PRESSURE PSIA	TEMPERATURE DEGREES RANKINE	FLOAT PRESSURE PSIG
2342.5	0	2357.2	459.7	0.50
2506.6	32	2521.3	491.7	1.56
2691.2	68	2705.9	527.7	2.75
2807.7	90.7	2822.4	550.4	3.50
2855.3	100	2870.0	559.7	3.80
2906.6	110	2921.3	569.7	4.13

Assuming the gas in the cylinder has cold soaked at 0 degrees F prior to take-off and must land in the water, a minimum float pressure of 0.5 psig is selected. Using a 780 cu. in. cylinder a pressure of 2342.5 psig is required. If the gas in the cylinder were heated to 110° and the float deployed, the pressure in the float would be 4.13 psig. It is desirable that the float pressure not exceed 3 or 3.5 psig. One solution to this problem is to vary the charge in the cylinder for summer and winter operations. Pressure could be increased for winter operations and decreased for summer operations.

Problems were encountered in transferring loads between the float and the 4 aircraft frames adjacent to the float. Gussets were provided at each end of the float to carry loads to the end frames. These gussets were generally slack and when loaded tended to tear away from the float causing leaks.

Cost analysis of the hard point provisions in the aircraft for float attachment revealed that complex tooling would be required. Such attachments would be costly so a preliminary study of an alternate, less costly method was made using belly band interconnects between floats.

Recommendations

In the emergency flotation system development follow-on effort it is recommended that work be done to resolve the problem of pressure buildup lag due to slow warm-up of the cooled gas. More inflation tests should be conducted to determine float pressure profile as a function of time. Demonstrations of aspirated systems should be conducted as a possible solution to the pressure lag problem. In addition it is a lighter weight system and inflation time is shorter.

The summer/winter gas cylinder pressure charging procedure should be investigated in an effort to resolve the wide variance in cylinder pressure due to ambient temperature changes. Cool gas generators should be investigated further for their advantages in this application.

Kevlar wound aluminum gas cylinders, the same as presently used on LAMPS, were used for the tests. These cylinders are not qualified and will have to be changed. The cylinders which will be qualified for LAMPS are planned to be used on the H-46 for commonality.

Float design changes should be made to resolve the problem of inlet gas jet damage by methods other than the inlet sock which could possibly restrict inlet gas flow. Methods of attaching the structural attachment girth should be studied to eliminate load concentrations which have caused tears and leaks on the test floats. New means of attaching the floats to the aircraft should be developed to reduce cost, weight and load concentrations present in the existing design. The float should be moved aft on the aircraft approximately 15 inches and attachments made to only 3 frames rather than 4. This will eliminate the problem gussets required at both ends of the float for carrying loads over the spherical end caps to the aircraft frames.

APPENDIX A
TEST PLAN
EMERGENCY FLOTATION SYSTEM

1. INTRODUCTION

Contract N62269-79-C-0707 was issued by the Naval Air Development Center to the Boeing Vertol Company for the development and testing of an emergency flotation system for the H-46 aircraft. This document sets forth a plan for fabrication, checkout, testing and demonstration of the operation and inflation of the flotation system.

2. STATEMENT OF WORK

Fabrication and demonstration of the flotation system shall consist of the following tasks:

a. Fabrication of a left hand float in accordance with specification D210-11584-1 and drawing SK-28474.

b. Installation of float on test fixture and system integration. (Test fixture, Pod assembly, Pressurization system and Electrical system will be supplied by Boeing Vertol)

c. Performance of electrical and pneumatic system checkout.

d. Performance of system operational demonstrations.

e. Photographic coverage.

3. FLOAT FABRICATION

The float shall be fabricated in accordance with SK28474-1 and -2 and applicable portions of specification D-210-11584-1. Relief valves and provisions for pressure measuring devices shall be provided as part of the floats. Bolt locations for girt attachments shall be coordinated with and shall match holes in test fixture SK-28473.

4. SYSTEM INTEGRATION

System components supplied by the Boeing Vertol Company as well as those components fabricated by the subcontractor shall be integrated into a total system. The floats shall be folded, installed in the pod and vacuum evacuated. The lower girth along with the lower pod shall be bolted to the test fixture first. Connection between the inlet nut plates in the float and the pressurization system interfaces shall be made by inserting bolts from inside the test fixture. Once the pressurization connections are made, the upper girth and upper pod hinge shall be bolted to the pod fixture utilizing vacuum as required.

Wiring shall be connected to the squibs on the pressure cylinders and to a 24 volt D.C. electric source. The water sensing device shall be connected in series to the squib also. A container of water shall be supplied, into which the hose from the water sensor can be immersed.

5. SYSTEMS CHECKOUT

Prior to connecting the wires to the squibs, a continuity check shall be made of all circuits with the switches in their various positions. Wiring diagram (Figure 1 and system schematic Figure 2) shall be referred to. A functional check of the systems shall be performed as follows:

5.1 System Test Functional Check

With the battery installed and one spare squib connected to the control box squib leads, the test circuit shall be checked as follows:

a. Verify that arm/test switch is in Off position.

b. Verify that semi-automatic switch is in Off position.

c. Verify that rotor speed switch is in High position.

d. Apply power to system.

e. Place arm/test switch in Test position.

f. Check test light on.

g. Verify that squib did not fire.

h. Return test switch to Off position.

i. Place ammeter in test circuit.

j. Place arm/test switch in Test position and measure current.

k. Verify that current does not exceed 2 amps.

5.2 Automatic Firing Functional Check

The system shall be checked for automatic firing function. With the spare squib remaining attached to the squib leads, the firing system shall be demonstrated as follows:

a. Verify that arm/test switch is in Off position.

b. Verify that semi-automatic switch is in Off position.

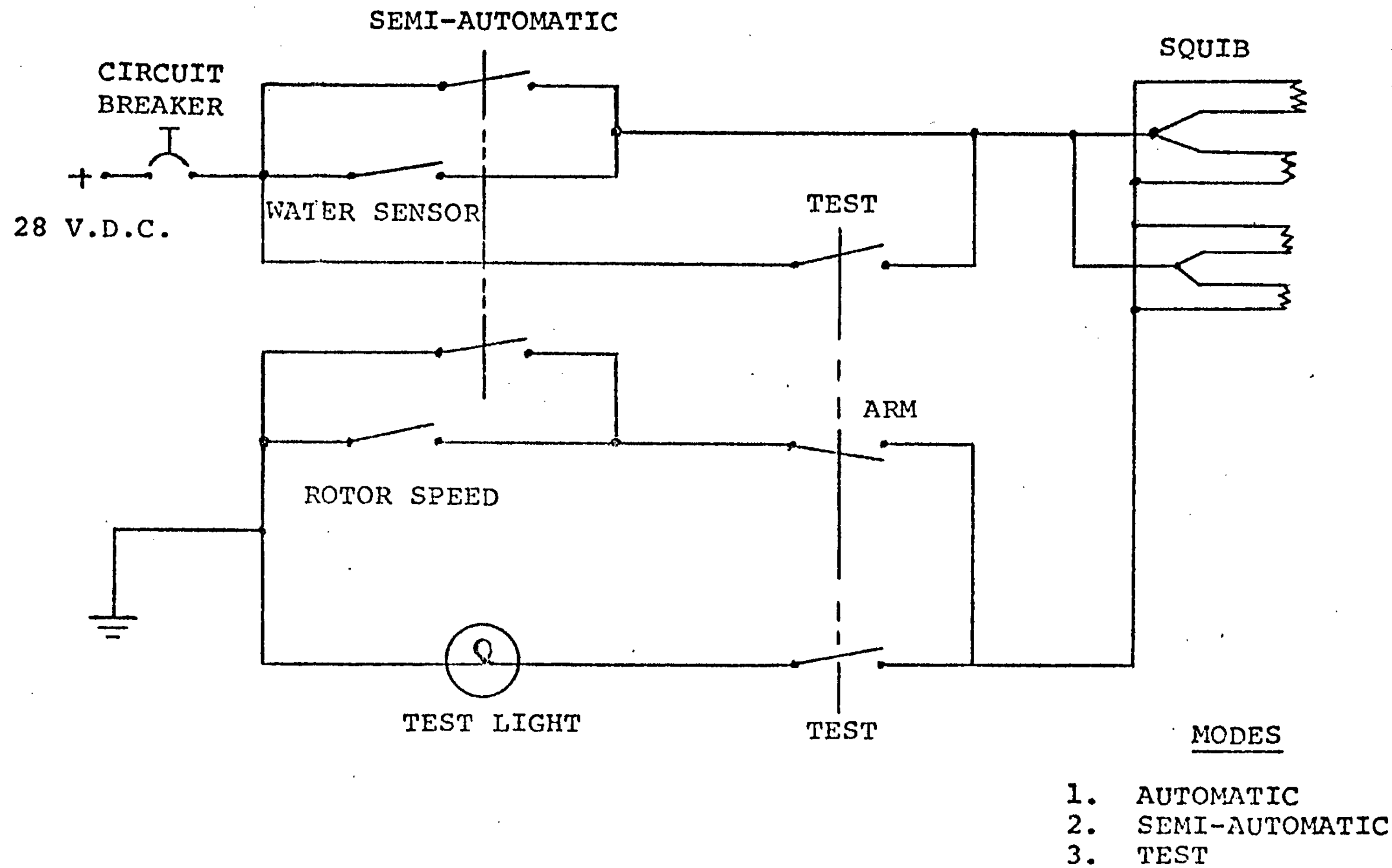


Figure 1. Electrical Schematic.

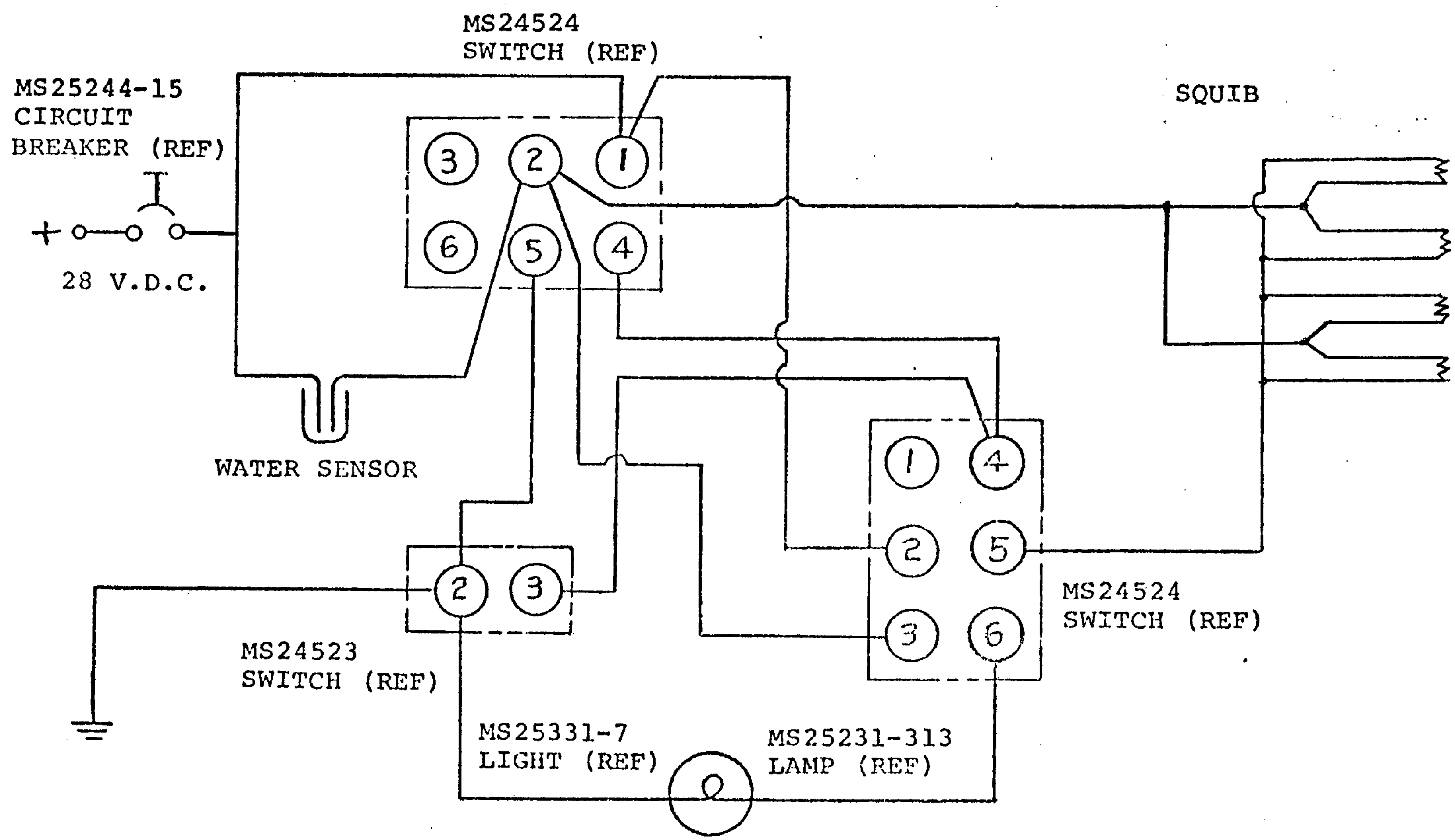


Figure 2. Wiring Diagram.

c. Verify that rotor speed switch is in High position.

d. Apply power to system.

e. Place arm/test switch in the Arm position.

f. Verify that squib did not fire.

g. Place water in water sensor container.

h. Place rotor speed switch in low position.

i. Verify that squib fired.

5.3 Semi-Automatic Firing Functional Check

The system shall be checked for semi-automatic firing function. Remove the water sensor container or disconnect water sensing wiring. The fired squib from the previous test shall be replaced and the firing system shall be demonstrated as follows:

a. Verify that the arm/test switch is in the Off position.

b. Verify that the semi-automatic switch is in the Off position.

c. Verify that the rotor speed switch is in the High position.

d. Apply power to system.

e. Place arm/test switch in Arm position.

f. Verify that squib did not fire.

g. Place semi-automatic switch in On position.

h. Place rotor speed switch in Low position.

i. Verify that squib fired.

5.4 Aspirator Efficiency Check

Each aspirator is supplied with provisions for positioning the drive rake in 3 locations. An efficiency check shall be made at each of the three locations to determine the best location for the rake. Various methods may be used including a flow meter or inflation of the float. One aspirator shall be used and if the float is used only one cell of the float need be inflated. The ratio of ambient air to compressed gas shall be determined for each of the 3 rake locations. If the float is used, the amount of gas required to inflate the cell to a specific pressure, at least 2.5 psi, shall be compared for each rake location. Rake ports not in use shall be plugged. Inflation time from time of system initiation to reaching the desired pressure shall be recorded.

6. SYSTEM OPERATIONAL DEMONSTRATION

After completion of all system checks complete system operational demonstrations shall be performed. A minimum of 6 demonstrations shall be performed as follows:

1. Direct compressed gas semi-automatic firing.
2. Direct compressed gas automatic firing.
3. Direct compressed gas manual release
4. Aspirated air semi-automatic firing.
5. Aspirated air automatic firing.
6. Aspirated air manual release.

6.1 Direct Compressed Gas Semi-automatic System Demonstration

The right and left floats shall be installed as described in paragraph 4. The system shall be demonstrated in the semi-automatic mode as follows:

a. Verify that arm/test switch is in Off position.

b. Verify that semi-automatic switch is in Off position.

c. Verify that rotor speed switch is in High position.

d. Apply power to system.

e. Place arm/test switch in Test position.

f. Verify test lamp is lit.

g. Return test switch to Off position.

h. Place arm/test switch in Arm position.

i. Place semi-automatic switch in On position.

j. Place rotor speed switch in Low position.

k. Verify squib has fired and floats have been deployed.

l. Record time required from system initiation to full inflation of floats.

m. Record pressure in both floats and if and when relief valves opened.

n. Examine float, pod and fixture assembly for damage.

o. Verify all cylinders were fully discharged by checking cylinder pressure.

6.2 Direct Compressed Gas Automatic System Demonstration

Floats shall be deflated, vacuum evacuated, repacked in the pods and installed by inserting new frangible aluminum hinge pins in the upper hinges. Frangible disks and electrical squibs in the nitrogen cylinders shall be replaced and the cylinders recharged to 3000 psi of dry nitrogen. The system shall be demonstrated in the automatic mode as follows:

a. Verify arm/test switch is in Off position.

b. Verify semi-automatic switch is in Off position.

c. Verify rotor speed switch in in High position.

d. Apply power to system.

e. Place arm/test switch in Test position.

f. Verify test lamp is lit.

g. Return test switch to Off position.

h. Place arm/test switch in Arm position.

i. Fill water sensor container with water.

j. Place rotor speed switch in Low position.

k. Verify squibs have fired and floats have been inflated.

l. Record time required from system initiation to full inflation of floats.

m. Record pressure in both floats and if and when relief valves opened.

n. Examine floats, pods and test fixture for damage.

o. Verify all cylinders were fully discharged by checking cylinder pressure.

6.3 Direct Compressed Gas Manual System Demonstration

Floats shall be deflated, vacuum evacuated, repacked in the pods and installed by inserting new frangible aluminum hinge pins in the upper hinges. Frangible disks in the nitrogen cylinders shall be replaced and the cylinders recharged to 3000 psi of dry nitrogen. Squibs need not be replaced. The system shall be demonstrated in the manual mode as follows:

a. Connect lanyards to the 4 nitrogen cylinders.

b. Using 2 to 4 test personnel, pull the 4 release lanyards.

c. Record time required from system initiation to full inflation of floats.

d. Record pressure in both floats and if and when relief valves opened.

e. Examine float, pod and test fixture for damage.

f. Verify that all cylinders were fully discharged by checking cylinder pressure.

6.4 Aspirated Air, Semi-automatic System Demonstration

Prior to performing the aspirated system demonstrations, the plumbing from the pressure cylinders must be modified. The 4 lines attached to the 4 direct pressure inlets at the float cells must be removed from the system plumbing and replaced with 4 new lines which will attach between the system plumbing and the aspirators as per drawing SK-28488. Wires for initiating the nitrogen cylinder squibs shall be connected to only one cylinder for the forward pair of aspirators and only one cylinder for the aft pair of aspirators. The 2 cylinders shall be charged to only 2500 psi of dry nitrogen after replacing squibs and frangible disks. Repacking and installation of floats shall be the same as for previous demonstrations. The system shall be demonstrated in the semi-automatic mode as follows:

a. Verify that arm/test switch is in Off position.

b. Verify that semi-automatic switch is in Off position.

c. Verify that rotor speed switch is in High position.

d. Apply power to system.

e. Place arm/test switch in Test position.

f. Verify test lamp is lit.

g. Return test switch to Off position.

h. Place arm/test switch in Arm position.

i. Place semi-automatic switch in On position.

j. Place rotor speed switch in Low position.

k. Verify squib has fired and floats have been deployed.

l. Record time required from system initiation to full inflation of floats.

m. Record pressure in both floats and when and if relief valves opened.

o. Verify all cylinders were fully discharged by checking cylinder pressure.

6.5 <u>Aspirated Air Automatic System Demonstration</u>

Floats shall be deflated, repacked and installed as for previous demonstrations. Squibs and disks shall be replaced in 2 cylinders, one each for forward and aft aspirators. Only these 2 cylinders shall be wired. The cylinders shall be charged to only 2500 psi of dry nitrogen. The system shall be demonstrated in the automatic mode as follows:

a. Verify arm/test switch is in Off position.

b. Verify semi-automatic switch is in Off position.

c. Verify rotor speed switch is in High position.

d. Apply power to system.

e. Place arm/test switch in Test position.

f. Verify test lamp is lit.

g. Return test switch to Off position.

h. Place arm/test switch in Arm position.

i. Fill water sensor container with water.

j. Place rotor speed switch in Low position.

k. Verify squibs have fired and floats have been inflated.

l. Record time required from system initiation to full inflation of floats.

m. Record pressure in both floats and when and if relief valves opened.

o. Verify all cylinders were fully discharged by checking cylinder pressure.

6.6 <u>Aspirated Air Manual System Demonstration</u>

Floats shall be deflated, repacked and installed as for previous demonstrations. Disks shall be replaced in 2 cylinders, one each for forward and aft aspirators. Squibs are not required. Cylinders shall be charged to only 2500 psi of dry nitrogen. The system shall be demonstrated in the manual mode as follows:

a. Connect lanyards to the 2 charged cylinders.

b. Using 1 or 2 test personnel, pull the 2 release lanyards.

c. Record time required from system initiation to full inflation of floats.

d. Record pressure in both floats and if and when the relief valves opened.

e. Examine float, pod and test fixture for damage.

f. Verify that all cylinders were fully discharged by checking cylinder pressure.

7. <u>PHOTOGRAPHIC COVERAGE</u>

Still photographs, using black and white film, shall be taken of the test set-up and of the test demonstrations as follows:

a. Three views of the overall test set-up

b. Two views of the control panel

c. Two views of the manual controls

d. Three views of the test specimen prior to life raft deployment demonstration test

e. Three views of the test specimen after life raft deployment demonstration test

f. Close-up views (as necessary) of any damage or distortion

Two sets of 5" X 7" glossy black and white prints shall be supplied of each shot taken.

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