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Survey and Analysis of Rotorcraft Flotation Systems

May 1996

Final Report

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16. Abstract

The primary goals of this study were (1) to evaluate rotorcraft flotation system performance in water related incidents and accidents and (2) to identify areas of potential improvements of rotorcraft flotation system operation and occupant fatality reduction. Four tasks were conducted: a survey of both civilian and U.S. Navy rotorcraft flotation technology, a review of civilian flotation accident and incident data, definition of generic flotation system improvements, and evaluation of available analytical methods for assessing flotation system performance. This study suggested upgrades of the civil regulations and potential design improvements to current deployable flotation systems. Further development work is required to determine the effectiveness of the proposed design improvements. Existing analytical methods for four significant aspects of the water landing sequence were described.

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LIST OF ABBREVIATIONS AND SYMBOLS

AC	Advisory Circular
AIDS	Accident/Incident Data System
ATA	Air Transport Association
CFR	Code of Federal Regulations
FAA	Federal Aviation Administration
FAATC	Federal Aviation Administration Technical Center
FAR	Federal Aviation Regulations
ft/s	feet per second
GSC	Galaxy Scientific Corporation
GTOW	Gross Takeoff Weight
HIC	Head Injury Criterion
HV	Height-Velocity
kts	Knots (Nautical Miles per Hour)
lbs	pounds
MAGW	Maximum Allowable Gross Weight
MLG	Main Landing Gear
MSC	MacNeal-Schwendler Corporation
NAWCADWAR	Naval Air Warfare Center Aircraft Division Warminster
NTSB	National Transportation Safety Board
PFD	Personal Flotation Device
psig	gauge pressure (pounds per square inch)
SDR	Service Difficulty Report
SI	Service Instruction
TSO	Technical Standard Order
WAFAC	Wave Forces Analysis Capability

EXECUTIVE SUMMARY

The objective of this study was to evaluate rotorcraft flotation system performance in water related incidents and accidents and to identify areas of potential improvement with regard to rotorcraft flotation system operation and occupant fatality reduction. The four tasks were conducted: a survey of civilian and U.S. Navy rotorcraft flotation technology, a review of civilian flotation accident and incident data, definition of generic flotation system improvements, and evaluation of available analytical methods for assessing flotation system performance.

Current civil regulatory requirements for flotation systems were reviewed and summarized. The water ditching environment was reviewed and the various civil rotorcraft configurations were categorized. The flotation technology survey was conducted through meetings and correspondence with rotorcraft manufacturers and U.S. Navy flotation experts. The results of the flotation technology survey were then categorized and reviewed for various representative helicopters. Float system data are presented by rotorcraft weight class and landing gear configuration.

Flotation system performance data were obtained from the FAA Accident/Incident Data System (AIDS) and Service Difficulty Reports (SDRs), the National Transportation Safety Board (NTSB), and manufacturer records. These data were analyzed to identify trends in flotation system performance. The flotation equipment performance was reviewed using current regulatory requirements. Survivable water landing conditions that exceed the current regulatory envelope for ditchings were also identified.

Generic design improvements to current flotation systems were suggested. Updates to current regulations were suggested. The design improvements are intended to address areas identified in the performance data review and include use of auxiliary floats as well as a refined arming and activation system. After review of the performance data and state-of-the-art system technology, four complexities associated with analytical modeling of the ditching sequence were identified. These were buoyancy and stability, wave action, water entry, and structural damage. Various existing analytical methods were investigated for their treatment.

1. INTRODUCTION.

This study is part of the Federal Aviation Administration's (FAA) ongoing effort to improve rotorcraft safety. The ditching and water impact environment for rotorcraft are unique and warrant much attention. Occupant drowning has been identified by researchers as a significant postimpact hazard (references 1 and 2) despite the presence of rotorcraft flotation equipment. This equipment is intended to keep a ditching rotorcraft afloat and in adequate trim until occupant evacuation. In the ditchings examined in the referenced studies, the performance of rotorcraft flotation equipment was inadequate. Drownings were reported in many survivable impacts. Improved float performance could have enhanced occupant survivability.

The objective of this study was to evaluate rotorcraft flotation system performance in water related incidents and accidents and to identify areas of potential improvement regarding rotorcraft flotation system operation and occupant fatality reduction. Four tasks were identified to achieve this goal:

a. Flotation Technology Survey: A survey was conducted of civilian and U.S. Navy rotorcraft flotation technology.

b. Flotation Performance Data Review: A review of civilian data on the performance of flotation equipment in accidents and incidents was conducted. Maintenance data were reviewed to identify any operational deficiencies that may affect flotation equipment performance.

c. Generic Flotation System Definition: Generic flotation system improvements were defined. These system improvements incorporate the most effective features described in Task A, as well as address deficiencies identified in Task B.

d. Evaluation of Relevant Analytical Methods: An evaluation was conducted to determine the applicability of available analytical methods in assessing flotation system performance.

Civilian and U.S. Navy equipment and performance data were used in this study. Some proprietary performance data from the U.S. Navy which were used are not presented.

This report documents the work performed in support of the four tasks listed above. A background section discusses the current civil regulatory requirements for flotation systems, the water ditching environment, and the various current rotorcraft configurations. The results of the flotation technology survey are presented and discussed. Flotation system performance data are analyzed from the following sources: FAA Accident/Incident Data System (AIDS) and Service Difficulty Reports (SDRs), National Transportation Safety Board (NTSB), and manufacturer records. Generic improvements to current flotation systems are presented, including suggested updates to current regulations. The problems associated with analytical modeling of the ditching sequence are outlined and various available methods are discussed. Finally, conclusions are presented.

2. BACKGROUND.

This section presents a summary of the relevant Federal Aviation Regulations (FARs) and methods by which rotorcraft manufacturers certify that their aircraft and associated flotation equipment comply with regulations. In addition, the water landing environment is discussed and an overview is given of the current U.S. civilian helicopter fleet.

2.1 FARs.

Ditching regulations for both normal and transport category rotorcraft are included in FAR Parts 27 and 29 (references 3 and 4). In addition, Advisory Circulars (AC) 27-1 and 29-2A (references 5 and 6) are provided by the FAA as guidance for the rotorcraft manufacturers in complying with the FARs. The regulations are concerned primarily with rotorcraft water impact, flotation characteristics, occupant egress, and occupant survival. The objective is to minimize the possibility of immediate injury and maximize occupant egress during a ditching. The FARs address these issues by defining water impact conditions that an airframe design must withstand in a ditching, providing requirements for emergency exits and emergency equipment, and requiring the demonstration of the design's ditching stability and flotation characteristics. The ditching impact conditions for both normal and transport category rotorcraft are:

a. Longitudinal velocity $\leq$ 50 ft/s.

b. Vertical velocity $\leq$ 5 ft/s.

c. Yaw angle $\leq$ 15 degrees.

d. Sea state $\leq$ 8-ft wave height.

e. Aircraft landing forced by power loss with all other controls/systems functioning properly (references 5 and 6).

Rotorcraft ditching certification is not required unless requested by the applicant (references 5 and 6). The regulations require demonstration of the flotation and trim requirements under "reasonably probable water conditions," which the FAA has determined to be Sea State 4. The details of these water conditions are discussed in section 2.3. Certification may be demonstrated either by model testing or comparisons with similarly configured rotorcraft already certified.

Upon ditching, the regulations require that the rotorcraft flotation time and trim be adequate to allow the occupants to exit safely and board life rafts. For a rotorcraft to become certified for ditching, the FARs (references 3 and 4) require that 150 percent buoyancy of the rotorcraft gross weight be provided for single floats and 160 percent for multiple floats. At least one emergency exit on each side of the fuselage must remain above the water line. To maintain these flotation and trim requirements, the rotorcraft may be equipped with emergency flotation devices. The flotation systems must be designed so that the floats do not interfere with, or obstruct, the exits when inflated.

Occupant water survival equipment is only required for extended overwater operations. This is defined as any operation occurring more than 50 nautical miles from the nearest shoreline and more than 50 nautical miles from an offshore heliport. The ACs recommend, however, that ditching certification be done with the maximum required ditching equipment regardless of the possible operational use. When applicable, the FARs require a minimum of a life preserver for each occupant, two life rafts, and a long-range signaling device. The life rafts must be stowed near exits and attached to the rotorcraft by a static line when deployed. The life preservers must be within easy reach of each occupant while seated.

Because it is common for rotorcraft manufacturers to deliver aircraft with unfinished interiors, the FAA permits a "segmented" certification of cabin interiors and stowage provisions for ditching equipment. The rotorcraft manufacturer is then required to show compliance with the flotation time, trim, and emergency exit requirements, and the purchaser must demonstrate compliance with the equipment provisions and egress requirements after the interior is completed. Rotorcraft manufacturers may also establish a "generic" interior for use in ditching certification. This interior may then be modified by either a supplemental type certificate or other FAA approval.

2.2 ROTORCRAFT DITCHING SUBSTANTIATION.

Compliance with ditching requirements is generally demonstrated through either model testing or comparison with similarly configured rotorcraft. Full-scale tests have been used by some civilian and military rotorcraft manufacturers, but for the most part these tests are costly and potentially hazardous to the personnel involved. Model tests have proven to be an economical means of examining varying ditching conditions and rotorcraft configurations (such as landing gear up or down, reference 7) so that operational limitations can be determined. The FAA has recognized the value of model tests and permits their use in demonstrating satisfactory water entry, flotation, and trim characteristics upon successful correlation between model and flight test data. Emergency ditching procedures may be derived from such tests.

The ACs suggest that water entry model tests be performed to determine the optimum pitch angle and forward velocity for ditching in a calm sea. They also require "entry procedures" for the highest sea state be demonstrated. The entry procedures describe the recommended part of the wave on which to land. Although procedures should be established for all possible engine operating conditions, the water entry test will verify only the most critical condition (usually all engines inoperative). The impact conditions used in the water entry tests are summarized as follows:

a. For entry in a calm sea:

(1) Pitch Angle: the optimum pitch angle, with consideration for pitch angle variations that would reasonably be expected to occur.

(2) Forward Velocity: ranging from zero up to points A and B in the Height-Velocity (HV) diagram (see figure 1).

(3) Vertical Velocity: 5 ft/s.

(4) Yaw Angle: up to 15 degrees.

b. For entry into the maximum sea state:

(1) Pitch Angle: the optimum pitch angle, with consideration for pitch angle variations that would reasonably be expected to occur.

(2) Forward Velocity: the forward speed defined by points A and B of the HV diagram (see figure 1) reduced by the wind speed associated with the sea state.

(3) Vertical Velocity: 5 ft/s.

(4) Yaw Angle: up to 15 degrees.

An example of typical HV diagram is shown in figure 1 (reference 8). HV diagrams define "avoid" curves which enclose those hazardous combinations of altitude and forward velocity which should be avoided in an autorotation. The shaded regions in figure 1 show these areas; the unshaded show the allowable operating regions. Points A and B, in figure 1, are referred to as the "knee" of the HV diagram in the ACs and refers to the combination of altitude and velocity which defines the most critical of the allowable operating ranges.

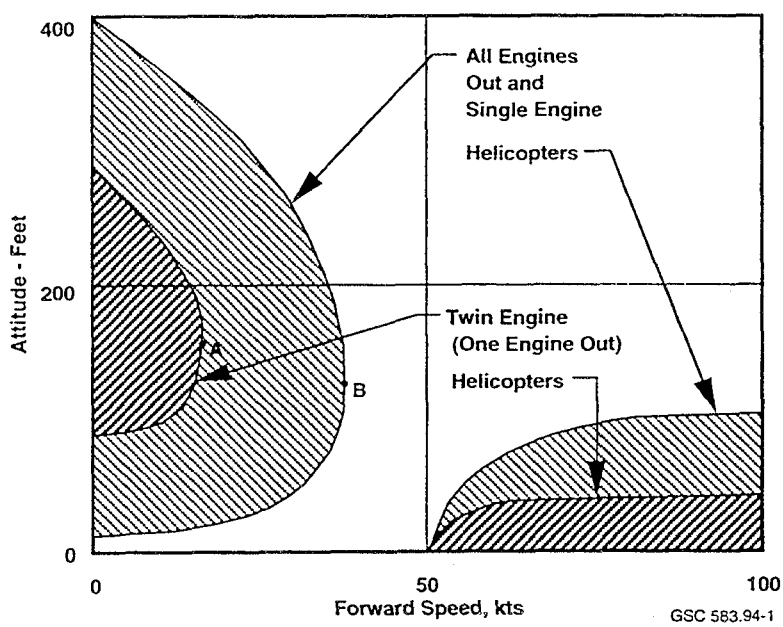


FIGURE 1. TYPICAL HEIGHT—VELOCITY (HV) DIAGRAM

The water impact tests, when performed, measure the structural integrity of the float system attachment hardware for both deflated and stowed as well as fully inflated floats (unless in-flight inflation is prohibited). Expected damage or failures either caused by the water impact, such as failure of windows, doors, skin, or panels, should be evaluated during the model water entry tests and stability tests or analysis.

The ACs also discuss the evaluation criteria for the emergency flotation system's inflation and structural integrity. Although the most critical float compartment must be deflated to meet the current standard, the design of the inflation system should minimize the probability of improper or asymmetric inflation. The use of the following are suggested in the ACs to comply with this requirement:

a. single inflation bottle or multiple inflation bottles interconnected,

b. redundant inflation actuation systems, and

c. mechanical backup if the primary actuation system is electrical. (A secondary electrical actuation system may also be used if sufficient electrical system independence and reliability can be shown.)

The inflation system should also be safeguarded against inadvertent float deployment during flight conditions. The recommended method of demonstrating this safeguard is to provide a separate flotation system arming circuit that must be activated. Other features called for by the ACs regarding the evaluation of inflation methodologies are as follows:

a. Establish maximum airspeeds, determined by rotorcraft flight characteristics, for in-flight deployment of floats (unless in-flight deployment is not permitted).

b. Inflation time from actuation to neutral buoyancy should be short enough to prevent more than partial submergence of the rotorcraft if inflation is initiated upon water contact.

c. Provide a means of checking and calibrating the inflation bottles before takeoff.

d. Provide a means of minimizing the possibility of overinflation.

e. Substantiate ability of floats to inflate without puncture when subjected to actual water pressures.

For the structural integrity of the floats, the ACs recommend the evaluation of air loads during inflation and after fully inflated for the most critical flight conditions. They also recommend the evaluation of water loads with fully inflated floats during water impact for those rotorcraft designed to deploy floats before water entry or during inflation after water impact for those rotorcraft prohibiting float deployment before water entry. Amendments 26-27 and 29-30 revised FARs 27.563 and 29.563 to add structural strength standards applicable to new rotorcraft float designs.

For those rotorcraft which have critical occupant egress capabilities as a result of life raft storage locations and/or emergency exit locations, an actual demonstration may be required to verify satisfactory deployment of life rafts, occupant egress, and boarding of the life rafts. The demonstration may be performed by immersing a full-scale rotorcraft into a calm body of water.

2.3 ROTORCRAFT WATER LANDING ENVIRONMENT.

There are several factors affecting the performance of a rotorcraft and its emergency flotation system during a ditching accident. The aircraft altitude at which the need to ditch becomes apparent and imminent, aircraft attitude and velocity, and availability of backup systems are factors that must be considered in assessing the performance of the floats. Postimpact factors must also be considered in the design of emergency flotation systems and the evaluation of their performance. Drowning has been identified as a more significant hazard than impact related injuries in accidents on water (references 1, 2). Once the occupants have survived the water impact, factors such as the availability of emergency exits and survival equipment, water temperature, and sea state affect their survival.

Sea state codes have been defined and accepted by the World Meteorological Organization to standardize the general severity of wind and wave conditions. The codes, taken from reference 6 and shown in table 1, are based on a combination of wave heights and wind speeds. The FAA uses the sea state codes to help establish a uniform performance standard for designing rotorcraft and emergency flotation systems leading to ditching configuration approvals. The rules for flotation establish a satisfactory level of stability under "reasonably probable water conditions." The FAA has determined that Sea State 4 is representative of such water conditions. This means upon impact into water with wave heights of 4 to 8 feet and corresponding wind speeds of 17 to 21 kts, the rotorcraft is expected to enter the water safely and to maintain sufficient buoyancy and trim, even with likely damages, to allow the occupants to exit the aircraft promptly and safely.

Figure 2 shows a postulated capsizing sequence for a rotorcraft equipped with emergency floats and immersed in a breaking wave. The overturning is initiated when one float comes out of the water, as shown in sequence 4, and a couple is created which exceeds the static righting moment of the helicopter (reference 8). The capsizing sequence shown is for a rotorcraft which is parallel to the breaking wave. For sea states up to 4, the depicted flotation system should be designed to prevent one of the floats from losing contact with the water.

TABLE 1. SEA STATE CODES (WORLD METEOROLOGICAL ORGANIZATION)

Sea State Code	Description of Sea	Significant Wave Height		Wind Speed (kts)
		Meters	Feet	
0	Calm (Glassy)	0	0	0-3
1	Calm (Rippled)	0 to 0.1	0 to 1/3	4-6
2	Smooth (Wavelets)	0.1 to 0.5	1/3 to 1 2/3	7-10
3	Slight	0.5 to 1.25	1 2/3 to 4	11-16
4	Moderate	1.25 to 2.5	4 to 8	17-21
5	Rough	2.5 to 4	8 to 13	22-27
6	Very Rough	4 to 6	13 to 20	28-47
7	High	6 to 9	20 to 30	48-55
8	Very High	9 to 14	30 to 45	56-63
9	Phenomenal	Over 14	Over 45	64-118

Note: Sea state codes are taken from reference 6.

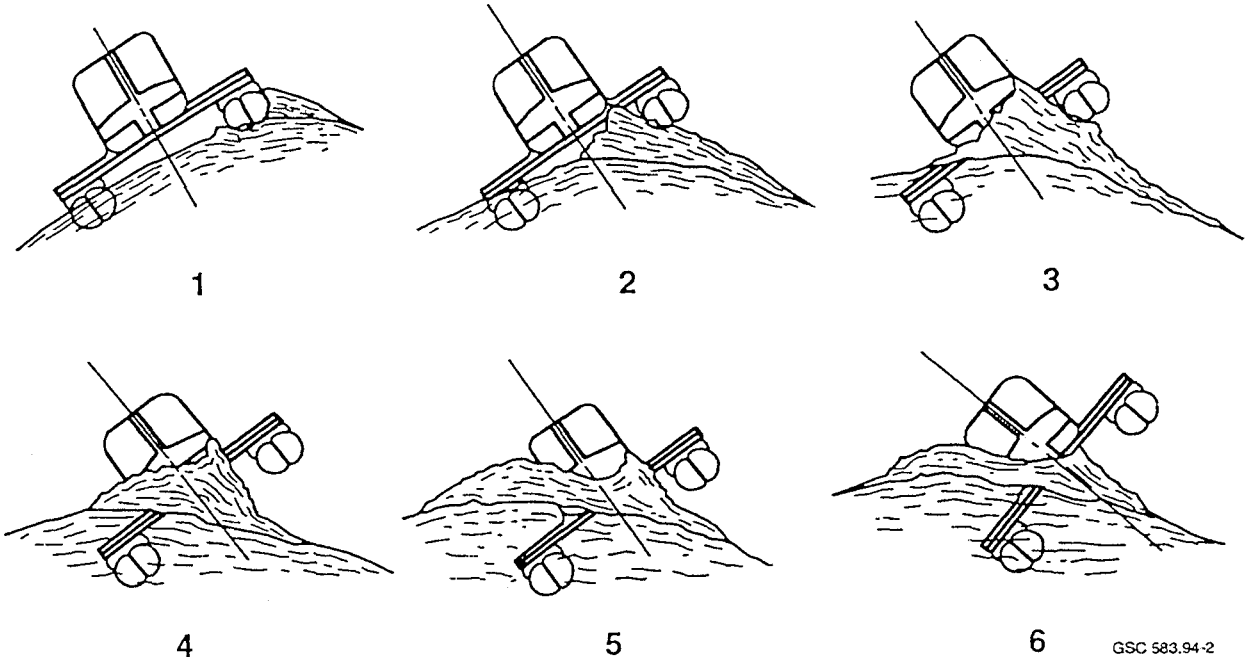


FIGURE 2. TYPICAL ROTORCRAFT CAPSIZING SEQUENCE

2.4 U.S. CIVILIAN ROTORCRAFT FLEET.

The design and construction of the emergency flotation systems are highly dependent on the rotorcraft landing gear configuration. This, in turn, is dependent on the overall weight of the rotorcraft. Generally, the lighter weight aircraft are configured with skid landing gear, and the heavier aircraft are configured with either fixed or retractable wheel landing gear. Table 2 lists the distribution of rotorcraft for each weight class as of December 1991. The data were obtained from

the 1992 Helicopter Annual publication (reference 9) and represent the best estimate of active civil rotorcraft in the United States. For this study, the rotorcraft weight categories used were

a. Weight Class A—less than 2,500 lbs
b. Weight Class B—2,501 to 6,000 lbs
c. Weight Class C—6,001 to 12,500 lbs
d. Weight Class D—above 12,500 lbs

Aircraft within weight classes A and B correspond to FAR Part 27 rotorcraft, and those within weight classes C and D correspond to FAR Part 29 rotorcraft.

As shown in table 2, as of December of 1991, there were 9,421 civilian rotorcraft registered in the United States. The predominant group of rotorcraft was weight class B, representing 52.8 percent of the total fleet. Of these, the Bell 206 model was the most popular, representing 2,030 of the 4,977 (41.0 percent) of the weight class B rotorcraft. Weight class as C and D rotorcraft were the least common, representing 10.8 and 3.3 percent of the entire fleet, respectively.

TABLE 2. DISTRIBUTION OF CIVIL ROTORCRAFT FLEET BY MODEL AND WEIGHT CLASS AS OF DECEMBER 1991

WEIGHT CLASS	A	B	C	D
MAXIMUM GROSS TAKEOFF WEIGHT (lbs)	< 2,500	2,501-6,000	6,001-12,500	> 12,500
MANUFACTURER AND MODEL (number registered in United States shown in parentheses)	Bell 47 (1,422) Brantly B2B (149) Robinson R-22 (657) Schweizer 269 (885)	Aerospatiale 315, 316, 318, 319, 341, 350, 355 (588) Agusta 109 (62) Bell 206 (2,030) Enstrom F-28, 280 (481) Brantly 305 (16) MBB 105 (210) MDHC 500 (792) Rogerson/Hiller UH-12, FH-1100 (798)	Aerospatiale 360, 365 (41) Bell 204, 205, 212, 222, 412, UH-1 (494) Boeing HUP, H21 (16) MBB BK117 (120) Sikorsky S-51, S-52, S-55, S-62, S-76 (347)	Aerospatiale 330, 332 (10) Bell 214, 301 (27) Boeing 107, 234, 360 (21) Sikorsky S-58, S-61, S-64, S-70, S-72 (247) Westland 30 (8)
TOTAL (Percentage of Fleet)	3,113 (33.0 %)	4,977 (52.8 %)	1,018 (10.8 %)	313 (3.3 %)

3. FLOTATION TECHNOLOGY SURVEY.

The demand for rotorcraft emergency flotation systems escalated significantly in the mid-1980s as a result of increased overwater operations by the offshore oil drilling industry and the desire to dispense with fixed amphibious bag type floats. Since their introduction, there have been several improvements in the design and construction of the float systems, including the fabric material strength-to-weight ratios, reliability, durability, serviceability, maintainability, and ease of installation and removal. This section provides an overview of the current technology for emergency flotation systems used on commercial and military rotorcraft and serves as a preface to the later discussions of float system performance and recommended system improvements.

In general, emergency flotation systems are comprised of four major components:

a. Inflatable flotation bags.
b. Inflation devices and systems.
c. Flotation mounts and bag covers.
d. Controls.

There are several system dependent variables associated with flotation system design such as the number of float bags, float compartments, inflation devices, float bag material, method of inflation, type of gas used for inflation, aircraft operating limitations, effect on overall rotorcraft weight and center of gravity, and stability in the water. This survey investigated the float system description, operation, installation and maintenance, and methods of certification for the four rotorcraft models shown in table 3. These four rotorcraft models were selected because they were representative with regard to rotorcraft weight and float system configuration. Also, sufficient data were available for these rotorcraft to support the survey.

TABLE 3. ROTORCRAFT MODELS IN FLOAT TECHNOLOGY SURVEY

Model	Maximum Allowable Gross Weight (MAGW) (lbs)	Weight Class (MAGW)(reference 1)
Bell 206	3,200	B (2,501 - 6,000 lbs)
Bell 222	8,250	C (6,001 - 12,500 lbs)
Sikorsky S-76	11,400	C (6,001 - 12,500 lbs)
U.S. Navy H-46	24,300	D (> 12,501 lbs)

Ideally, all four weight classes would have been considered in this survey; however, no emergency float data were obtained for weight class A (gross weight less than 2500 lb.) rotorcraft. This is because it is impractical for these rotorcraft to support the additional weight of the emergency float systems. Instead, they typically use the lighter, permanent, utility floats if their operations involve overwater flights. A large military rotorcraft was included to examine U.S. Navy equipment because of its similarity to the Boeing 234 helicopter.

3.1 SOURCES OF DATA.

The rotorcraft and float system manufacturers generally were reluctant to provide detailed information on the design and construction of the floats because of their proprietary nature. This limited the amount and detail of the data initially obtained. Data were also obtained from the emergency flotation systems' Service Instructions (SIs) for several representative rotorcraft. Emergency flotation system SIs were obtained for the Sikorsky S-76, Bell 222, and Bell 206 (references 10 to 15). The data on the Navy's H-46 were obtained from technical literature published by the Naval Air Development Center (references 16, 17). Additional flotation systems information was obtained from references 18 through 21.

3.2 FLOTATION SYSTEMS.

The data are categorized by the predominant characteristics of the float systems included in the survey (Bell 206, Bell 222, Sikorsky S-76, Navy H-46). The data are also presented in tabular format in appendix A. Illustrations of the rotorcraft with their flotation systems mounted are shown in appendix B.

3.2.1 System Description.

The emergency flotation systems are composed of inflatable flotation bags, inflation devices, flotation mounts and bag covers, and controls. In general, the floats are configured either as a skid-mounted or fuselage-mounted system, depending on the landing gear configuration.

3.2.1.1 Number of Floats.

The number of floats employed typically varies from two to six floats (one to three per side) with multiple cells per float. Multiple floats with several cells each are desirable as a precaution against one or more of the float cells failing to inflate or being punctured upon impact. Table 4 shows the buoyancy and number of floats for each system and the overall rotorcraft weight and mounting configuration. The Bell 222 is available in both skid and wheel landing gear configurations.

The required minimum buoyancy of 125 percent of the maximum allowable gross weight (MAGW) of the rotorcraft should be provided by a combination of floats and any sealed volumes within the fuselage. This allows for failure of the most critical cell and provides adequate buoyancy and stability for safe evacuation during emergency ditching operations. A system that provides a minimum buoyancy of 160 percent of the MAGW is considered adequate for takeoff from the water with the floats fully deployed.

In the case of the H-46 (for which FAA regulations do not apply) the buoyancy is only 100 percent of the MAGW of the rotorcraft. In designing the H-46 emergency flotation system, the Navy established the following performance requirements:

a. Keep fuselage afloat for a minimum of 10 minutes in a stable condition with a slightly nose-high attitude to permit occupant egress.

b. Keep fuselage afloat for three hours to permit aircraft recovery.

TABLE 4. BUOYANCY AND NUMBER OF FLOATS RELATIVE TO GROSS WEIGHT AND MOUNTING CONFIGURATION

Model	MAGW (lbs)	Mounting Configuration	Buoyancy (percent of gross weight)	Number of Floats
Bell 206	3200	Skid	160	6
Bell 222	8250	Skid or Fuselage	125*	4
Sikorsky S-76	11,400	Fuselage	141*	4
Navy H-46	24,300	Fuselage	100*	2

*Part of the buoyancy indicated for the Bell 222, S-76 and H-46 is provided by sealed internal volumes within the fuselage, such as fuel cells and sealed tailboom.

Table 4 shows the pattern of lighter weight models having skid mounted flotation systems and the heavier models having fuselage mounted systems.

Table 4 also shows a difference in the number of floats with increasing rotorcraft gross weights and for rotorcraft with fuselage mounted float systems. A skid landing gear configuration provides a convenient means of mounting the floats but may result in the helicopter riding higher above the water. Rotorcraft equipped with wheel landing gear, whether retractable or fixed, may require more sophisticated systems to store the floats. Fewer floats are typically found in the systems aboard heavier rotorcraft.

3.2.1.2 Float Location and Storage.

Emergency floats are stowed in a packed position and enclosed in some form of protective cover until activated. The floats tend to be positioned to produce a slightly nose-up attitude in water to prevent the cockpit and cabin from being submersed under water. The skid mounted systems tend to have very simple storage methods. Each float is folded and stored in a protective cover, typically made of a waterproof material such as nylon, and mounted on top of the skid landing gear. The float bag covers for skid mounted systems are fitted with snaps which pop open upon float deployment. An example of such a system is shown in figure B-1 for a later Bell 206 multicell emergency flotation system. The Bell 222, when configured with a skid landing gear, can also support this type of emergency float system. Typically, this method of mounting and storing floats weighs less per float than the fuselage-mounted floats.

The heavier rotorcraft that do not use skid landing gear require more sophisticated, and thus heavier, mounting systems. The Bell 222 (with retractable wheel landing gear), S-76 (retractable landing gear), and H-46 all have more sophisticated float bag storage compartments. The nose floats on the S-76 are stored inside fuselage skin flaps (see figure B-3), and the Bell 222 nose floats are stored within a fairing mounted beneath the forward fuselage (see figure B-2). These storage compartments are hinged on one side and remain attached to the fuselage upon deployment of the floats. The main landing gear (MLG) floats on the S-76 are stored inside the MLG doors, requiring

the doors to blow out to the full-up position upon deployment of the floats. To do this, a link connecting the doors to the MLG must be severed by a pyrotechnic charge.

In the case of the H-46, a float bag is stored in a pod on each side of the fuselage, as shown in figure B-4. The two pods are constructed of a rigid, lightweight material and are aerodynamic. Additional pods would add cost and reduce its flying performance. The H-46 is equipped with water ballast scoops on each side of the fuselage (figure B-4). Holes in the bottom of the scoops automatically regulate the amount of water taken into the scoop. The result is a counter-rotative moment that reduces or retards fuselage roll caused by wave action.

For simplicity and reliability, it is easier to compartmentalize the float bags rather than use many of them. In addition, sealed compartments within the fuselage, such as fuel tanks, are used to complement the buoyancy provided by the deployable floats.

3.2.1.3 Multiple-Cell Floats.

The use of multiple-cell float bags attempts to minimize the effects of a severe leak or rupture in one cell on the overall rotorcraft buoyancy and stability under wave action. It also prevents significant loss of buoyancy in the event a single cell does not inflate. Table 5 shows the buoyancy per cell and the total number of cells in each of the four flotation systems included in this survey. The total number of cells were calculated by multiplying the number of floats by the number of cells per float for each flotation system (appendix A).

TABLE 5. TOTAL NUMBER OF CELLS AND CELL BUOYANCY

Model	Number of Cells Per Float	Total Cells	Buoyancy per Cell (lbs)* (percent total buoyancy)	Net Buoyancy with One Cell Deflated* (percent total buoyancy)
Bell 206	1 (forward 4) 2 (rear 2)	8	640 (12.5%)	147.5
Bell 222	2 (nose 2) 5 (wing 2)	14	705 (6.8 %) (nose) 678 (6.6 %) (wing)	118
Sikorsky S-76	2 (all 4)	8	1450 (9.0 %) (nose) 1544 (9.6 %) (rear)	131
Navy H-46	2 (both 2)	4	4,375 (18 %)	82

*The buoyancy numbers provided are estimates assuming there is an equivalent volume per cell for each type of float.

Table 5 shows that a minimum of four cells are used in each float system investigated in this survey. When not considering the military rotorcraft, the minimum number of cells increases to eight. The loss of one cell from any of the three civilian flotation systems results in a loss of buoyancy ranging from 6.6 to 12.5 percent. The resulting net remaining buoyancy in the event of a single cell failure ranges from 118 to 147.5 percent.

Only 60.2 percent, 74.4 percent, and 72.0 percent, respectively, of the Bell 222, S-76, and H-46 total buoyancy is accounted for by the floats. The remaining buoyancy is accounted for by sealed volumes within the fuselage. For example, the Bell 222 uses a water-tight tailboom and fuel cells

for additional buoyancy. The flotation systems are designed and certified for the "worst case" scenario. Therefore, the required buoyancy is expressed as a percentage of the MAGW, and all fuel cells are considered to be full.

3.2.1.4 Float Material.

In general, floats are constructed of a strong, elastic material coated with a waterproof polymer. Typically, these materials are nylon with a urethane coating. Because the floats are repacked following each use and during maintenance and inspection, the materials used must be pliable to prevent cracking. The elasticity of the material must also be relatively independent of temperature so that the float bags and coating do not become brittle.

S-76 floats are constructed out of the nylon-urethane combination. The primary material of the Bell floats is nylon, but no data were obtained regarding the surface coating. The H-46 float bags are made of a urethane-coated Kevlar material. Kevlar has the benefit of being two-thirds the weight for an equivalent strength nylon fabric but is more expensive.

3.2.1.5 Flotation System Weight.

In addition to the amount of space required to mount and store emergency flotation systems, the overall weight of the system is a significant factor in its use for civilian rotorcraft. Emergency floats require a method of storage and protection while not in use, as well as a reliable method of rapid inflation when activated. The weight of each flotation system relative to the gross weight of the aircraft is presented in table 6 which shows that as the rotorcraft gross weight increases, the flotation system's weight decreases as a percentage of the vehicle's gross weight. This indicates that flotation system manufacturers were able to design systems capable of providing the additional buoyancy required by heavier rotorcraft without adding excessive weight to the rotorcraft. This is accomplished, in part, by using sealed internal volumes.

As an example, table 6 shows that the flotation system for the S-76 is 30.4 lbs lighter than the Bell 206, even though the S-76 requires significantly more buoyancy. The S-76 fuselage provides 25.6 percent of the total buoyancy, thus reducing the amount of buoyancy required by the deployable floats.

TABLE 6. FLOTATION SYSTEM WEIGHT AS A FUNCTION OF ROTORCRAFT GROSS WEIGHT

Model	Flotation System Weight (lb)	Rotorcraft Gross Weight (lb)	Percentage of Gross Weight (%)
Bell 206	144.4	3,200	4.5
Bell 222	209 (SKID)/ 223 (WHEEL)	8,250	2.5/2.7
Sikorsky S-76	114	11,400	1.0
Navy H-46	Unknown	24,300	Unknown

A high flotation system weight-to-rotorcraft-gross-weight ratio may explain the inability of lightweight rotorcraft to use current emergency flotation systems. Installing a typical skid mounted flotation system designed for a weight class B rotorcraft on a weight class A rotorcraft could result in a flotation system which accounts for over 10 percent of the vehicle's gross weight. The need for the development of emergency flotation systems designed specifically for weight class A rotorcraft needs to be evaluated, because these rotorcraft are commercially used extensively. Reference 9 identified 3113 weight class A rotorcraft registered in the United States, 33.0 percent of the civil rotorcraft fleet, in December 1991.

3.2.1.6 Inflation Devices.

Inflation devices, commonly referred to as bottles, store compressed gas at high pressures and are used to inflate the float bags rapidly. Although each system has a slightly different method of releasing the gas into the float bags, the bottles are typically "fired" by a pyrotechnic charge that punctures a diaphragm in the bottle, causing the gas to release. Use of multiple bottles is desirable in the event a single bottle does not fire. The military H-46 bottle, shown in figure 3, is designed to work without a pyrotechnic charge. In this case, a solid propellant is burned to warm the gas stored in the bottle, raising its pressure until a burst valve releases the gas into the float bags. One benefit of this type of inflation method is that it automatically adjusts the amount of solid propellant burned depending on the ambient temperature. This ensures that the gas supplied to the floats has a uniform and constant temperature and pressure regardless of the ambient temperature. The other systems are temperature dependent in that the pressure supplied to the floats will range anywhere from 1.5 to 2.25 psig depending on ambient conditions. In such a system, the pressure within the bottle must be adjusted to the ambient conditions before takeoff to ensure full inflation of the floats upon deployment.

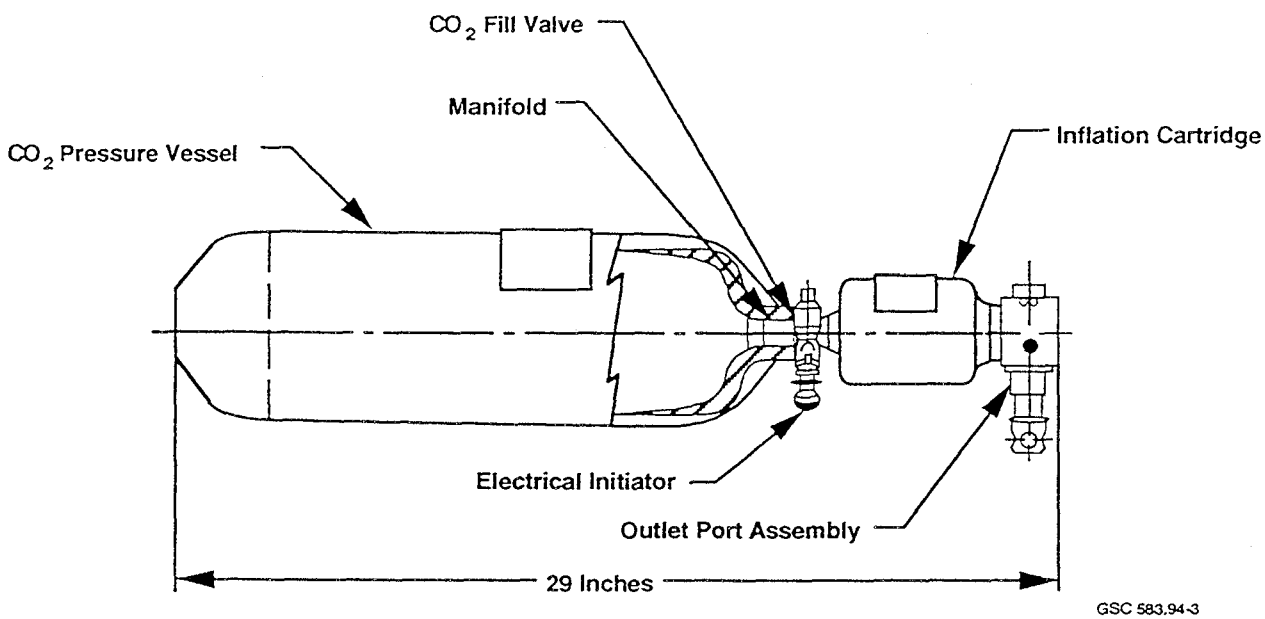


FIGURE 3. H-46 INFLATION BOTTLE

Table 7 lists the inflation device properties for the four flotation systems in this survey.

TABLE 7. INFLATION DEVICE PROPERTIES

Model	Number of Bottles	Gas	Bottle Pressure (psig)	Inflation Time (sec)	Float Pressure (psig)
Bell 206	2	Nitrogen	2,800–2,900	5	2.25
Bell 222	1	Nitrogen	2,850–3,100	6	2.25
Sikorsky S-76	4	Helium or Nitrogen	3,000	5*	0.75–3.5
Navy H-46	4	CO_2	5,500**	Unknown	2.25

*Sufficient buoyancy to keep the rotorcraft afloat is produced in 3 seconds.
**In the case of the H-46, the pressure increases to 5,500 psig during the burning of a solid propellant. At this time, the gas is released into the float bags.

Table 7 shows that three of the four flotation systems use multiple bottles. Some inflation devices are designed to inflate each side of the fuselage equally in the event that one bottle fails to fire. This is done by using a cross-feed arrangement of the bottles. If a single bottle does not fire, an equal amount of buoyancy will be lost on each side of the fuselage and the aircraft will remain in balance. This method of inflation is used on the S-76 and Bell 206 flotation systems. The Bell 222 has one bottle to inflate all four floats (14 cells), and therefore if it does not fire, none of the floats will inflate. This system does have a manual backup that may be activated after the rotorcraft has settled in water. The H-46 has one bottle for each of its four cells. Each bottle fills one entire cell so that in the event that an inflation device does not fire, the cell will not inflate.

The types of gases used to inflate the flotation systems are nitrogen, helium, and carbon dioxide. The nitrogen and helium gases are typically compressed to approximately 3,000 psig and expanded to approximately 2.25 psig in the inflated floats. The pressure of the compressed gas within the bottle (with the exception of the H-46 system) can be adjusted before takeoff to account for variations in ambient temperature. In the case of the S-76 system, nitrogen may be used in place of helium with minimal adverse effects on performance in terms of total buoyancy, inflation time, and ease of servicing. The H-46 flotation system uses a Kevlar reinforced aluminum pressure vessel containing pressurized/liquefied carbon dioxide.

Inflation times for the civilian flotation systems are under six seconds. The inflation time for the H-46 flotation system, initiated by the burning of a solid propellant, is unknown. The inflation times for the different systems cannot be immediately interpreted as being equivalent as their activation sequences differ. The Bell 206, S-76, and H-46 provide cockpit controls which allow for float activation by the pilot during flight if water impact becomes imminent. This allows the floats to deploy completely during low speed or hover before impact. The Bell 222 system activates the floats automatically only upon contact with the water surface. The floats will not be fully inflated until six seconds after impact. This is designed to prevent the floats from failing before impact, ensuring that all the floats will be available to provide buoyancy once the rotorcraft has entered the water. The details of the activation processes for all four flotation systems are discussed below.

3.2.2 System Operation.

The emergency flotation systems examined in this survey are controlled by an electrical inflation system which involves a two step activation process. The first step requires the inflation circuit to be armed before takeoff, landing, or whenever selected. This step is necessary to prevent inadvertent float activation. Float deployment during certain flight conditions (typically high-velocity flight) may cause an unsafe flying condition and may be limited by system design features. Therefore, FAA guidelines recommend that the inflation system be safeguarded against inadvertent activation by using a separate float arming circuit and other system design features.

In the second activation step, inflation is triggered by either a water contact sensor or a switch operated by the pilot. The Bell 206 has an activation trigger switch on the collective stick, as shown in figure 4. The Bell 222 system activates upon submersion of any two of the four water immersion switches. A manual backup handle is also provided, but cannot be activated until after impact as the helicopter may become uncontrollable (reference 10). The S-76 system has a firing switch on the cyclic stick. The H-46 system may be activated either by the pilot by a cabin-mounted normal/emergency switch, or by water level/inverted aircraft sensors.

As mentioned, float deployment during high-velocity flight can cause an unsafe flying condition. The systems that allow the pilot to initiate the inflation process by cabin-mounted activation switches or triggers (Bell 206, S-76, and H-46) have constraints that may limit the velocities during which the floats may be safely deployed. Table 8 shows the operating environment parameters for the four flotation systems.

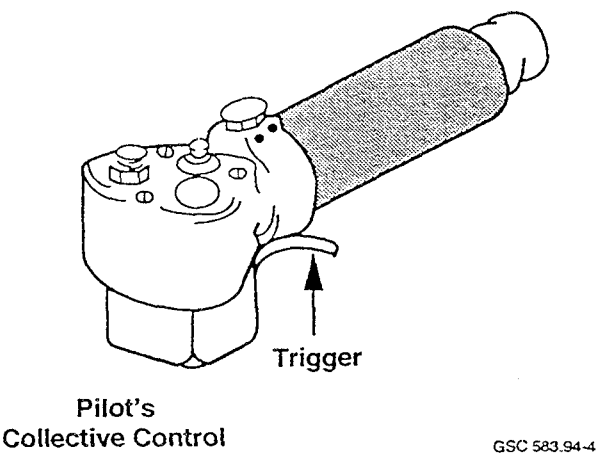


FIGURE 4. BELL 206 FLOAT ACTIVATION TRIGGER (REFERENCE 20)

TABLE 8. FLOTATION SYSTEM OPERATING ENVIRONMENT PARAMETERS

Model	Maximum Velocity for Deployment (kts)	Sea State
Bell 206	52	Unknown
Bell 222	Not Applicable (hover)	11
Sikorsky S-76	75	8
Navy H-46	Unknown	Unknown

As shown in table 8, the Bell 206 floats may not be activated during flight velocities exceeding 52 kts. Once the floats are inflated, however, the Bell 206 may be flown up to 70 kts without any adverse effects on the performance. In addition, autorotation may be performed for speeds under 61 kts. The Bell 222 is not designed to allow the pilot to activate the floats in flight. The Bell 222 may be ditched safely in wave heights not exceeding 11 feet with wind speeds up to 28 kts. With a single float cell deflated, it may be ditched in wave heights not exceeding 3.3 feet with wind speeds up to 12 kts. The S-76 flotation system requires speeds under 75 kts during and after deployment of the floats. In addition, the S-76 water entry speed must not exceed 33 kts. No data were available on the flight performance characteristics of the H-46 during and after deployment of its floats.

3.2.3 Installation, Service, Testing, and Maintenance.

Installation of the flotation system is performed either by the rotorcraft manufacturer during the manufacture of the rotorcraft or by the operator in the field as a factory kit. Rotorcraft operators are provided with a complete set of service instructions, including those for the installation and servicing of the emergency flotation system. Special features provided by commercial flotation system manufacturers may require different installation procedures, which would be provided to the operator upon purchase of the system. For example, a rapidly interchangeable system exists for the Bell 206 in which the floats can be taken off one aircraft and installed on another in approximately five minutes (reference 21). The only permanent weight which remains on the aircraft without the floats is a 15-lb. mounting kit. This type of system can have significant benefits in terms of initial purchasing costs, operating costs, and maintenance/servicing costs for an operator who does not have a full-time need for emergency floats for overwater operations.

Generally, system inspections are required on a preflight and 180-day (or 500-hour, whichever comes first) basis. The preflight inspection entails a visual check of the float bottle and its pressure; float bag covers; and inflation system valves, hoses, and electrical connections. The 180-day (500-hour) inspections require a complete float bag inflation test and inspection. To reduce the resources needed to conduct this test, air may be used in these tests rather than the standard compressed gas. Float bags that have exceeded 10 calendar years of service since original installation will continue to be tested under the regular 180-day test procedure. Any such float bag exceeding 10 calendar years of service, which requires maintenance or repair more extensive than a coating to seal fabric porosity, must be retired.

3.2.4 Method of Certification/Qualification.

Scaled models were used to determine flotation and stability characteristics for the Bell 222 (reference 7). Two Bell 222 models, 1/8 and 1/26 scales, were built to perform these tests. The models consisted of a fiber glass body, a floodable fuselage, and scaled internal volumes.

Initial flotation tests were performed to determine the static water line and overturning boundaries by floating the model at varying wave headings representing full-scale heights up to 30 feet and lengths up to 450 feet. Once the limiting conditions were observed, additional tests were performed at the same limiting sea condition with varying wind speeds up to 40 kts. This test sequence was then repeated with the most critical float not inflated to determine further operational limitations.

Ditching tests were also performed using the same models fitted with a scaled lifting main rotor. The models were instrumented with accelerometers. Horizontal, vertical, and longitudinal acceleration measurements were taken during each landing. Tests were repeated for varying forward speeds and attitudes, roll and yaw angles, and sea states until operational limitations, including ditching configurations, were defined. The results were then used to establish recommended ditching procedures which were included in the flight manual.

In the case of the H-46, the system was subjected to both component and full-scale tests. Initially, design verification tests were performed on the H-46 floats and pods in both 20- and 60-foot water test tanks. During these tests, the floats and pods were mounted to a fixture representing one side of the H-46 fuselage and tested for system deployment and float submergence. There were two types of full-scale tests. First, a series of 13 tests were performed in which the fuselage was both lowered and dropped into a body of water to test the water sensing float switch. The dynamic (drop) test involved the fuselage being raised to a height of approximately 1 ft and 10-degree nose-up pitch and then given a forward velocity of approximately 12 kts. The floats were set on automatic and deployed upon impact with the water. The second set of full-scale tests involved a 10-minute fuselage-sealed and three-hour fuselage-flooded tests. The purpose of these tests were to demonstrate that the flotation system could float an H-46 at a MAGW of 24,300 lbs for the 10-minute safe egress and the three-hour aircraft recovery periods.

4. FLOTATION SYSTEM PERFORMANCE SUMMARY.

Assessing the performance of emergency flotation systems is a necessary part of studying overall rotorcraft safety. The flotation system is a critical aspect of occupant postimpact survival as it is designed to maintain the stability of a rotorcraft in a water environment, thereby allowing time for the occupants to escape. The performance of rotorcraft flotation systems was investigated previously by evaluating accident data (reference 1). Although much was learned about float behavior, these data focused the float performance assessment on more severe occurrences. The impact conditions of those accidents often exceeded the FAA's ditching certification requirements. The goal of this performance summary was to include analysis of less severe incidents in the assessment to obtain a broader perspective of float performance during normal operations and identify areas of improvement in their design and construction.

Industry provided statistics on ditching incidents (references 22 and 23) for the years 1973 to 1983. One hundred and seventy-four rotorcraft ditchings occurred during this period, with 10 percent of the rotorcraft involved not being equipped with floats. The data are given in table 9.

TABLE 9. DITCHING DATA OBTAINED FROM ROTORCRAFT MANUFACTURERS

Category	Ditchings	On Board	Evacuated Safely
FAR 27	140	295	292
FAR 29	34	223	223
Total	174	518	515

Table 9 data indicate that only three fatalities resulted from these ditchings. The data also show a combined annual rate of approximately 17 ditchings per year for FARs 27 and 29 rotorcraft during this period. Since the source of these data did not discuss the accidents individually, no detailed review of the accidents was possible.

4.1 REVIEW OF NTSB DATA.

NTSB accident data were collected and analyzed in reference 1. The focus of that report was to evaluate

a. Impact conditions.
b. Occupant survivability hazards.
c. Rotorcraft and occupant flotation equipment performance.

Reference 1 examined sixty-seven accidents that occurred between 1982 and 1989, and these were reviewed for this study. Of these, 7 were determined to be nonsurvivable, 3 were partially survivable, and 57 were survivable. In addition to the FAA ditching certification requirements, a criterion of ±15-degree pitch was used in the reference 1 study to help eliminate extreme impact conditions from consideration. Water impact under these conditions would be expected to allow the rotorcraft to maintain stability by remaining upright long enough for occupant egress.

Only four accidents met these ditching conditions; the remainder were categorized as water impacts. Twenty-one of these accidents were classified as almost ditchings because they met all conditions except the vertical velocity.

Figure 5 shows the crash survivability for water landings for which impact velocities were reconstructed in the reference 1 study. Of the 67 water landings, impact velocities for 66 cases were identified and shown. Note that a survivable accident is defined as an impact which produces accelerations that do not exceed human tolerance limits, and the rotorcraft maintains a livable volume. Impact velocity envelopes are typically used to describe a survivable crash environment.

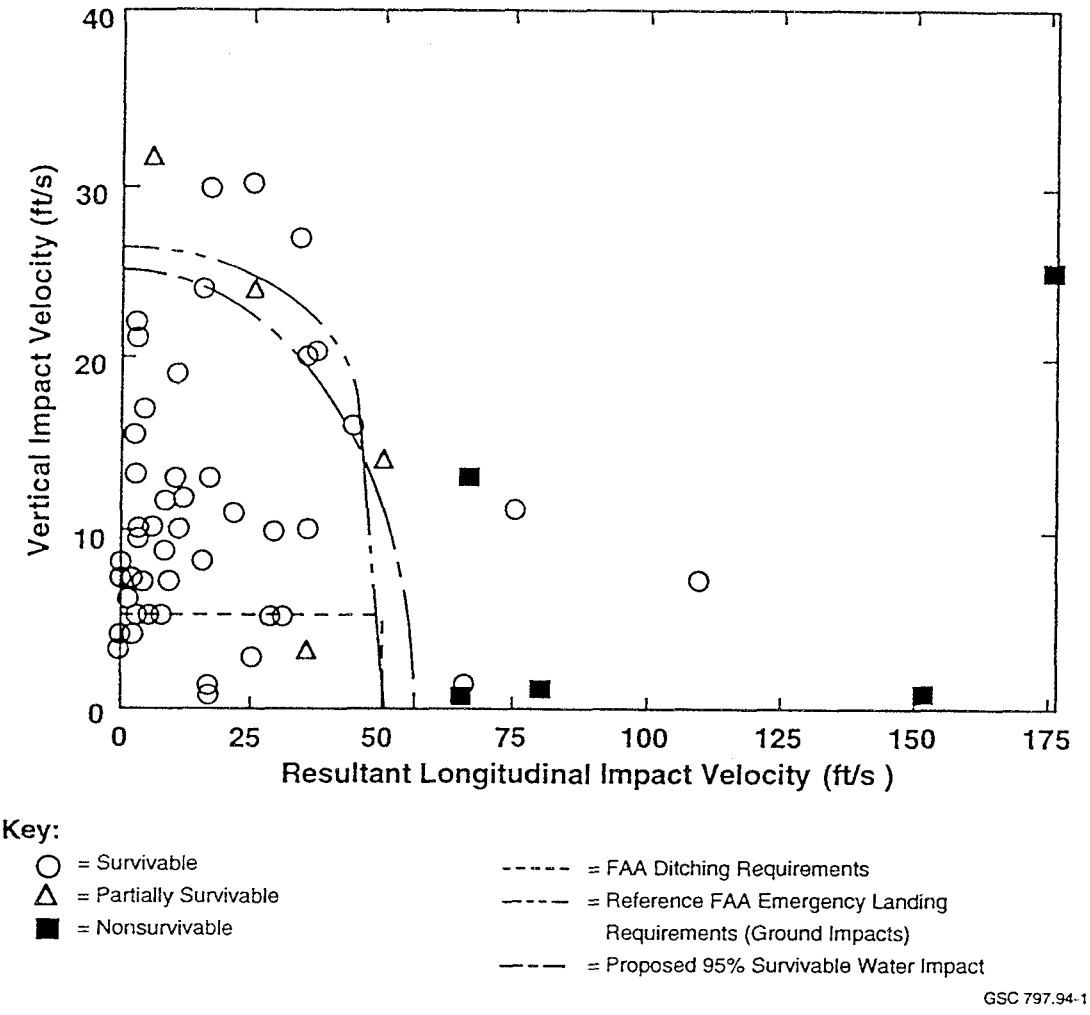
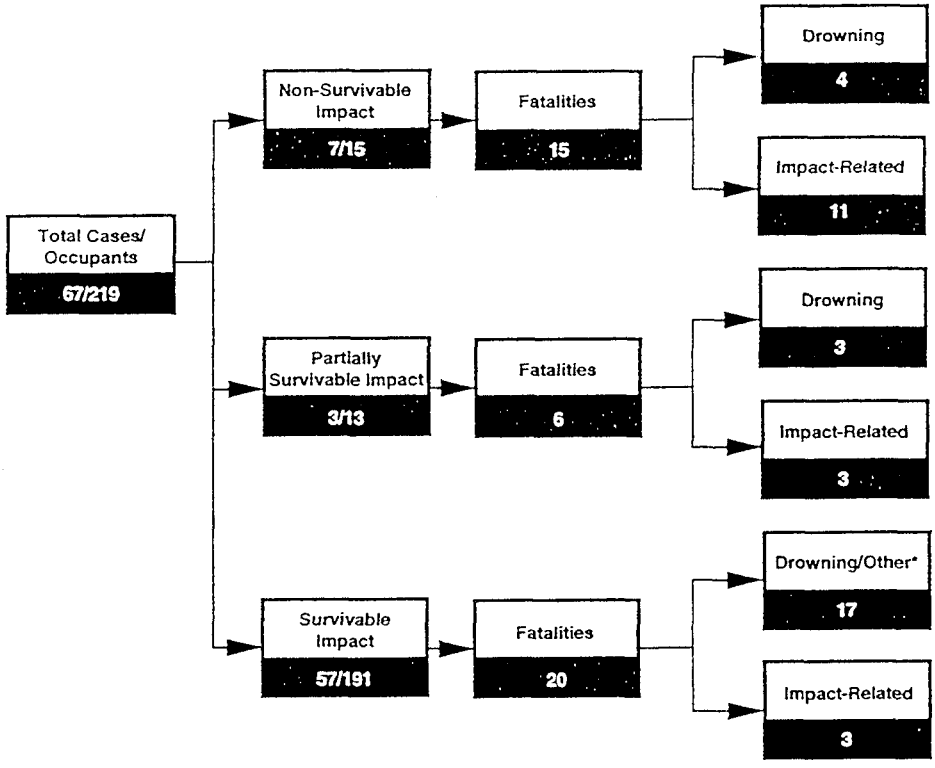


FIGURE 5. ROTORCRAFT CRASH SURVIVABILITY FOR WATER LANDINGS, 1982–1989

Figure 5 also shows a significant number of accidents beyond the survivable envelope defined by FAA ditching requirements. This may be a result of rotorcraft being designed to prevent occupant injury for increasingly severe impact conditions.

The envelope displayed in figure 5 for FAA emergency landing requirements for ground impacts was drawn by connecting lines from two data points of 26 ft/s vertical and 50 ft/s longitudinal. Newly certified rotorcraft must meet a dynamic seat test requirement which specifies these two velocities at certain pitch, roll, and yaw values.

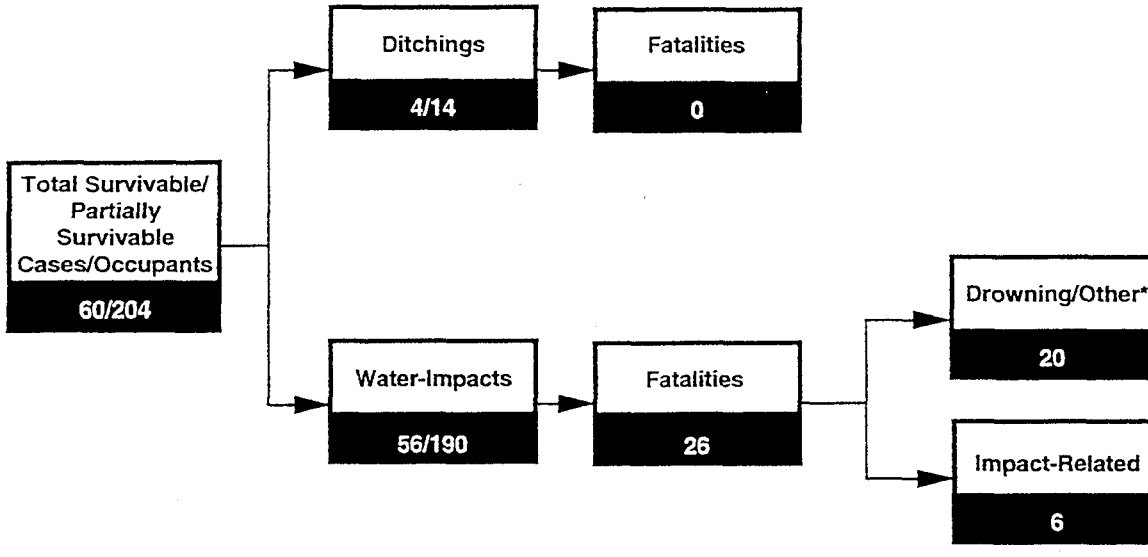
Postcrash hazards were found to cause more fatalities than impact trauma. Out of a total of 219 occupants, there were 41 fatalities where 26 of these occurred in survivable accidents. Figure 6(a) provides a summary of occupant survivability and causes of fatalities. For survivable accidents, most fatalities were due to drowning. There was also one case in which the fatality resulted from excessive exposure to cold water. These data show that the occupants are generally surviving the



*Death from exposure

GSC 797.94-2

FIGURE 6(a). CAUSES OF FATALITIES FOR WATER LANDINGS



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*Death from exposure

FIGURE 6(b). CAUSES OF FATALITIES FOR SURVIVABLE AND PARTIALLY SURVIVABLE DITCHINGS AND WATER IMPACTS

impacts, but are drowning as a result of postimpact difficulties. Figure 6(b) presents the breakdown of ditching occurrences and water impacts for the 60 survivable and partially survivable cases given in figure 6(a). As shown in the figure, there were no fatalities resulting from the four accidents which satisfied the FAA's ditching requirements. For the 56 cases involving the more severe impact conditions, there were only 6 trauma related fatalities out of 190 occupants (3 percent).

Figure 7 shows the causes of fatalities for survivable and partially survivable cases in which the rotorcraft impact velocities were known. As shown, occupants survived impacts in which the rotorcraft's vertical and longitudinal velocities far exceed the FAA's ditching envelope; however, the occupants were faced with postimpact difficulties such as exiting the rotorcraft, drowning, and exposure.

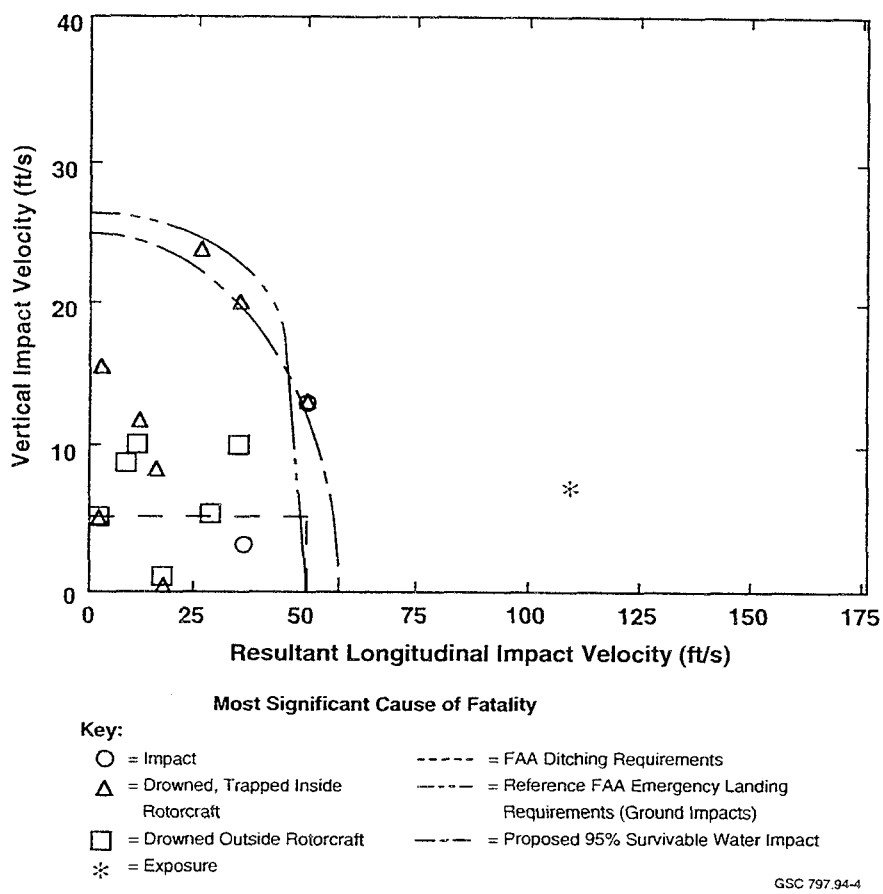


FIGURE 7. DISTRIBUTION OF CAUSE OF FATALITIES FOR WATER LANDINGS WITH KNOWN IMPACT VELOCITIES

An example of this is the "Drowned, Trapped Inside Rotorcraft" case at approximately 24 ft/s longitudinal and 24 ft/s vertical velocities. Here, the rotorcraft autorotated to the surface from an altitude of approximately 300 ft following a low main rotor RPM condition during landing. Although the floats were deployed successfully before impact, the rotorcraft overturned immediately and sank. Of the five occupants aboard the rotorcraft, four exited the aircraft and held

onto the floats, which separated on impact. The final passenger was unable to release the seat belt, and drowned.

The 95th-percentile survivable water impact velocities from reference 1 consisted of two data points of 25 ft/s vertical and 56 ft/s longitudinal. A curve was drawn connecting these two points to illustrate the survivable envelope for water impacts. The vertical velocity component is approximately the same for ground impact and water impact, but the longitudinal velocity for water impact is higher.

After analysis of the NTSB ditching and water impact data, four float performance problem areas were identified. These problems are rotorcraft overturning, float arming, improper equipment, and other float design related problems. The following sections address each of these. The accidents/cases referred to in these sections all refer to the survivable and partially survivable cases.

4.1.1 Rotorcraft Overturning.

As mentioned, drowning was the most common fatality among the 67 accidents in the database. Occupants survived even severe water impacts, but drowned after impact. Immediate overturning of the rotorcraft upon impact was the most common cause of occupant drownings in an otherwise survivable accident. Although no fatalities resulted from the four ditching incidents, three of these rotorcraft overturned immediately upon impact.

Of the 60 survivable and partially survivable accidents, 48 overturned (80 percent). Forty-one of these were immediate overturns (overturns occurring within 90 seconds of impact). Out of the 19 drownings that occurred, 11 occupants were trapped inside overturned rotorcraft. Each of the drownings in an overturned rotorcraft was void of documented impact trauma. This represents 8 percent of the 142 occupants that experienced an immediate overturn after landing. One occupant was trapped inside a rotorcraft which did not overturn; however, the drowning was partly caused by multiple rib fractures which inhibited the passenger's ability to exit the sinking rotorcraft.

The remaining seven passengers managed to escape the rotorcraft but drowned because of excessive sea states and fatigue. The majority of these drownings would have been prevented had the rotorcraft remained upright and afloat.

The size of the overturned rotorcraft can also have an effect on occupant egress and survivability during a water impact accident. There were 5 overturned rotorcraft out of 53 (9 percent) with 7 or less occupant seats in which 1 or more of the occupants was trapped inside. There were 4 overturned rotorcraft out of 7 (57 percent) with 10 or more occupant seats in which occupants were trapped inside (there were no cases in which the rotorcraft had 8 or 9 occupant seats). This may indicate that the larger rotorcraft may have a higher risk of occupant entrapment. This would be expected because of the higher occupants-to-exits ratio and greater distance to exits for some occupants. The greater the distance separating the occupant from the exit, the greater the chance of debris blocking the pathway to the exit. Disorientation becomes magnified in situations involving occupants trapped in an overturned rotorcraft, making it difficult for the occupant within a larger rotorcraft to even locate the exit.

Rotorcraft have a natural tendency to invert in water because of their relatively high center of gravity. Combining this inherent instability with wave action, high winds, and impacting the water at a significant velocity or improper attitude greatly increases the chance of capsizing and, therefore, the risk of entrapment. Figure 8 shows the most common causes for immediate rotorcraft overturning. The most common was the rotorcraft's impact attitude, accounting for 10 of the 24 rotorcraft which were equipped with floats and resulted in an immediate overturn.

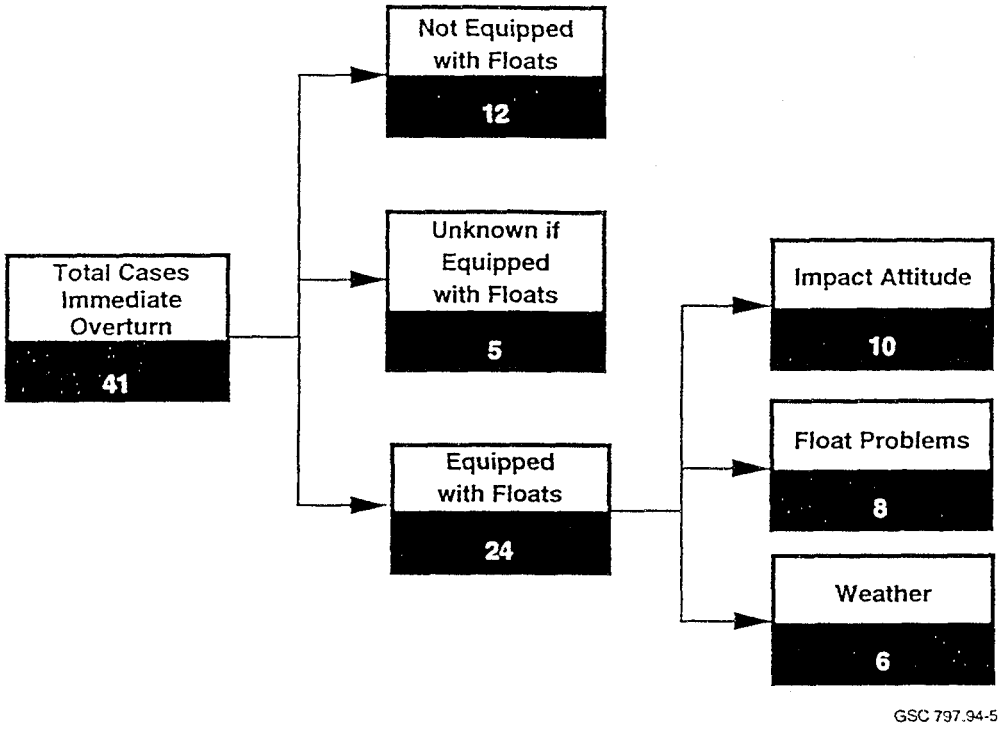


FIGURE 8. CAUSES OF ROTORCRAFT IMMEDIATE OVERTURNING

These cases are not necessarily the result of excessive impact angles. There were cases in which the roll, pitch, and yaw angles were within the FAA's ditching requirements, but other factors such as the rate at which the impact angles were changing at impact caused immediate overturn. Figure 9 presents the pitch-versus-roll angles for each of the overturn cases where the pitch and roll angles were known. The box drawn in figure 9 encompasses the pitch and roll envelope used to define the FAA's ditching requirements in reference 1.

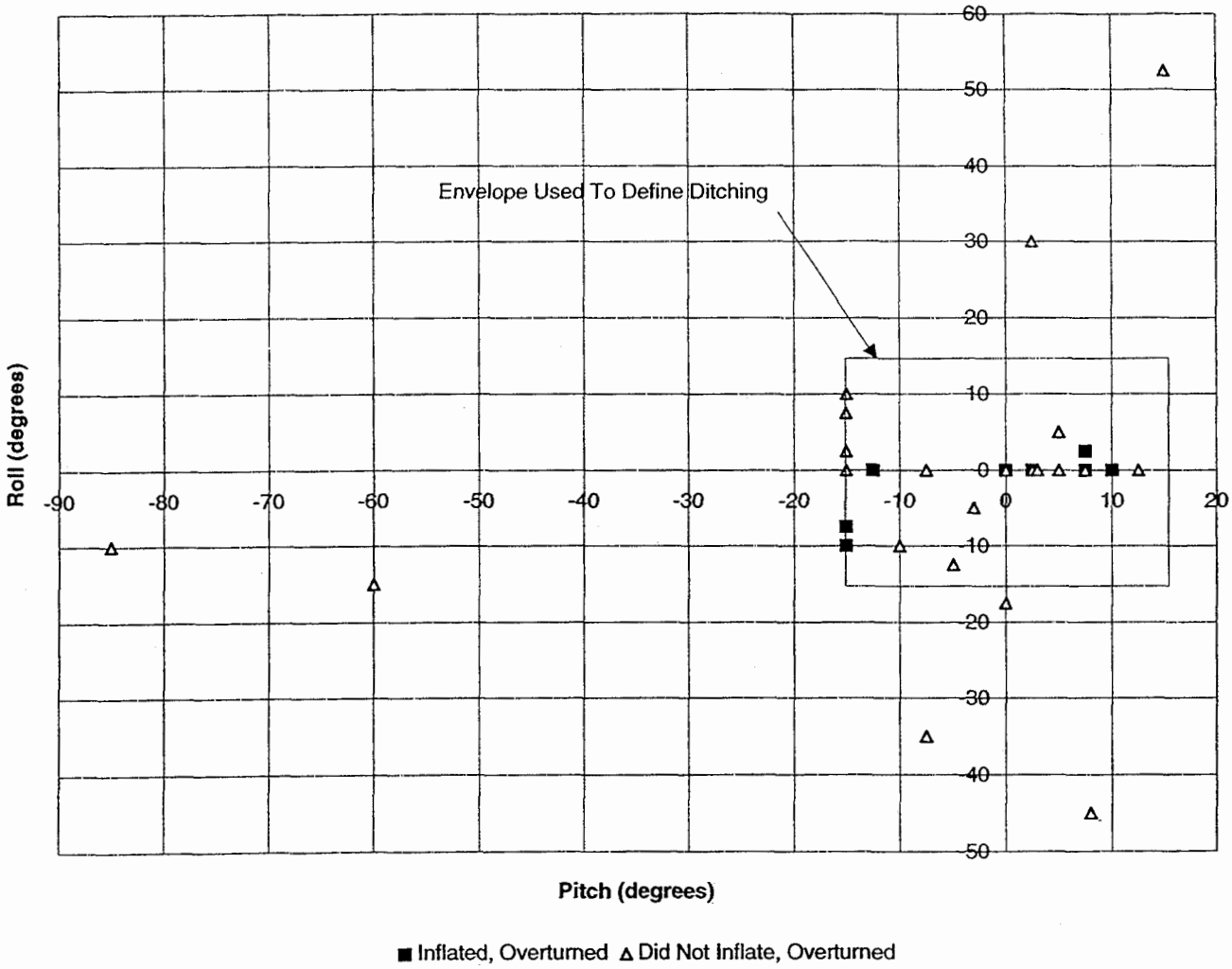


FIGURE 9. PITCH VERSUS ROLL ANGLE FOR OVERTURNS CAUSED BY IMPACT ATTITUDE

The 9 overturns in which the floats were deployed and survived the impact fell within this envelope. The majority of overturns that did not involve successful use of the floats fell within the envelope as well. Although rotorcraft are not designed to stay upright when the floats are not successfully deployed, these cases are included in figure 9 to show the need for more float-equipped rotorcraft.

Although only one of the overturns in which the floats were inflated was categorized as a ditching incident, five of the remaining eight were considered "near ditchings." These last impacts satisfied all FAA ditching requirements except the vertical velocity. The vertical velocities for these near ditchings varied from 5.2 to 23 ft/s. Thus overturns occurred after impacts which, though severe, were survivable and involved successful deployment of the floats.

Following is an example of an overturn occurring during a mild impact. The impact was completely level and trim (0 degree pitch, 0 degree roll, and 0 degree yaw), and the impact velocities were mild (5 ft/s vertical, 17 ft/s longitudinal, and 0 ft/s lateral). The pitch rate was enough to cause the rotorcraft to roll forward, end over end, causing the cabin to rest upside down.

Because rotorcraft are overturning during impact conditions which are not excessively severe and because the impact attitude cannot always be controlled, the most practical solution to this problem would be to return the rotorcraft to a position suitable for egress after it overturns. Two proposed designs will be presented in section 5.1 to accomplish this.

The second most common cause of rotorcraft immediate overturn was termed "float problems." Four of eight cases involved uneven float deployment, resulting from nondeployment in two cases and separation of floats on one side of the fuselage in the other two cases. The remaining four cases resulted from the floats not being armed, separation of the activation wires upon impact, separation of one float upon impact, and no response from the activation switch (the activation switch was not fully depressed). Arming and activation difficulties are discussed in more detail below.

Weather was also a problem in overturnings where the floats were successfully deployed. As discussed, the FAA has determined that Sea State 4 is representative of "reasonably probable water conditions" in which the rotorcraft is expected to maintain a satisfactory level of stability. Of the six weather related immediate overturnings, four cases were in conditions in which the wave heights and wind velocities were within this range of reasonably probable water conditions. The sea states for these four cases ranged from 2 to 4. Two of the four cases involved successful deployment of the floats. This demonstrates that the inherent instability of the rotorcraft is significant enough to cause an overturn in smooth to moderate sea states, even when the floats are successfully deployed.

4.1.2 Floats Not Armed.

The fact that many rotorcraft equipped with emergency flotation systems impact the water with the floats unarmed is a cause for concern. Of the 35 rotorcraft accidents occurring with rotorcraft known to have floats installed, 6 cases occurred in which the float system was known to be unarmed. Three of these occurred during the takeoff phase of flight. The altitude recorded during these three occurrences ranged from 70 to 100 feet, which allowed little time for the pilot to arm the system. Two cases occurred during cruise, and the final case occurred during the approach phase of flight. Although the range of altitudes for these cases was much higher (roughly 300 feet in each case), in two cases the pilot specifically mentioned the lack of time to arm the floats.

As mentioned, current flotation systems typically require a two-step process for inflation. First, the inflation circuit must be armed, and second, the inflation is triggered either by a water sensor or by a switch operated by the pilot. The FAA guidelines recommend that the inflation system be safeguarded against inadvertent activation by using a separate float arming circuit. Unfortunately, the pilot is often preoccupied with controlling and landing the rotorcraft during an emergency situation and may fail to arm the inflation system before the water landing.

One such example involved a common rotorcraft ditching scenario, a flight enroute to an oil rig in the Gulf of Mexico. The pilot stated that he was getting ready to arm the floats in preparation for a "school book" approach. The altitude and airspeed at this time was 300 feet at 60 MPH. The aircraft suddenly began a rapid descent, and although the pilot was aware of the need to arm the floats, he stated "I did not have time to even think about arming and inflating the floats." A second case involved a failed takeoff from an oil rig. The pilot stated that the floats "were not activated primarily because my effort was diverted to keeping the helicopter away from the structure."

In some cases, water impact is totally unexpected. One unexpected impact occurred during a flight to an oil rig. Because of limited visibility, the pilot was forced to keep the rotorcraft at a very low altitude to maintain visual contact with the drilling platform. The unexpected impact with the water occurred at approximately 118 ft/s longitudinal velocity and 7 ft/s vertical velocity. This resulted in one passenger fatality and serious injuries to two others.

It may be possible to make improvements to the float arming and activation systems. Recommended improved activation systems are discussed in chapter 5.

4.1.3 Rotorcraft Not Properly Equipped.

As noted, rotorcraft are not required to have floats installed unless ditching certification is requested by the applicant. The Advisory Circulars do not address the operational limits which require ditching certification. FAR Part 127.121 operating regulations (reference 25), however, require single-engine rotorcraft to be equipped with floats when operating overwater beyond the autorotation gliding distance from land. This regulation only applies to air carriers (flight for hire). Many overwater operations which are performed on a regular basis, do not require emergency flotation because the operations are within the autorotation distance to land. Unfortunately, many water impact accidents occur where the flight situation does not allow for autorotation, and the resulting damages and injuries could be mitigated with the use of floats.

Out of 60 survivable and partially survivable rotorcraft accidents, 14 rotorcraft (23 percent) did not have floats installed. Of these 14 cases, 5 rotorcraft were operating outside of what would be considered the autorotation distance from land. One of these cases was a personal flight, so the Part 127 regulation does not apply. This leaves four cases which appeared to be in violation of FAA regulations. It may be concluded that although existing FAA regulations are generally being followed, rotorcraft are being operated without being properly equipped with emergency floats.

Thirteen of the 14 rotorcraft without floats could have probably landed on land if the pilot had chosen to do so. However, when given a choice, pilots appear to prefer emergency landings on water. The common reasons stated for choosing the water landing included the presence of obstacles on land and the less severe impact on water. The situation is that the regulations permit rotorcraft to fly without floats when close to shore as long as the flight is over land. However the pilots prefer to emergency land in water, anyway, even without floats. Recommended regulatory upgrades regarding required ditching certification are discussed in section 5.3.

Emergency flotation equipment is available for all rotorcraft models. Because of the constraints on maximum takeoff weights for weight class A rotorcraft, the installation of emergency flotation systems becomes impractical, and therefore flotation systems are not installed. These rotorcraft are popular in low speed/low altitude missions such as overwater sightseeing, photography, and other types of observation flights. This represents a hazard, as the owner and/or operator does not have the benefit of using floats to assist in certifying the rotorcraft for ditching if so desired. All 7 weight class A rotorcraft included in the sample of 60 survivable and partially survivable accidents were not equipped with floats. This apparent lack of suitable equipment represents an area of flotation technology that needs to be addressed.

4.1.4 Other Float Problems.

In addition to the majority of the float problems discussed previously, such as rotorcraft overturning, float arming, and improper equipment, there were a variety of other float problems as summarized in figure 10. The three types of "other" problems were impact damage, activation failure, and uneven deployment.

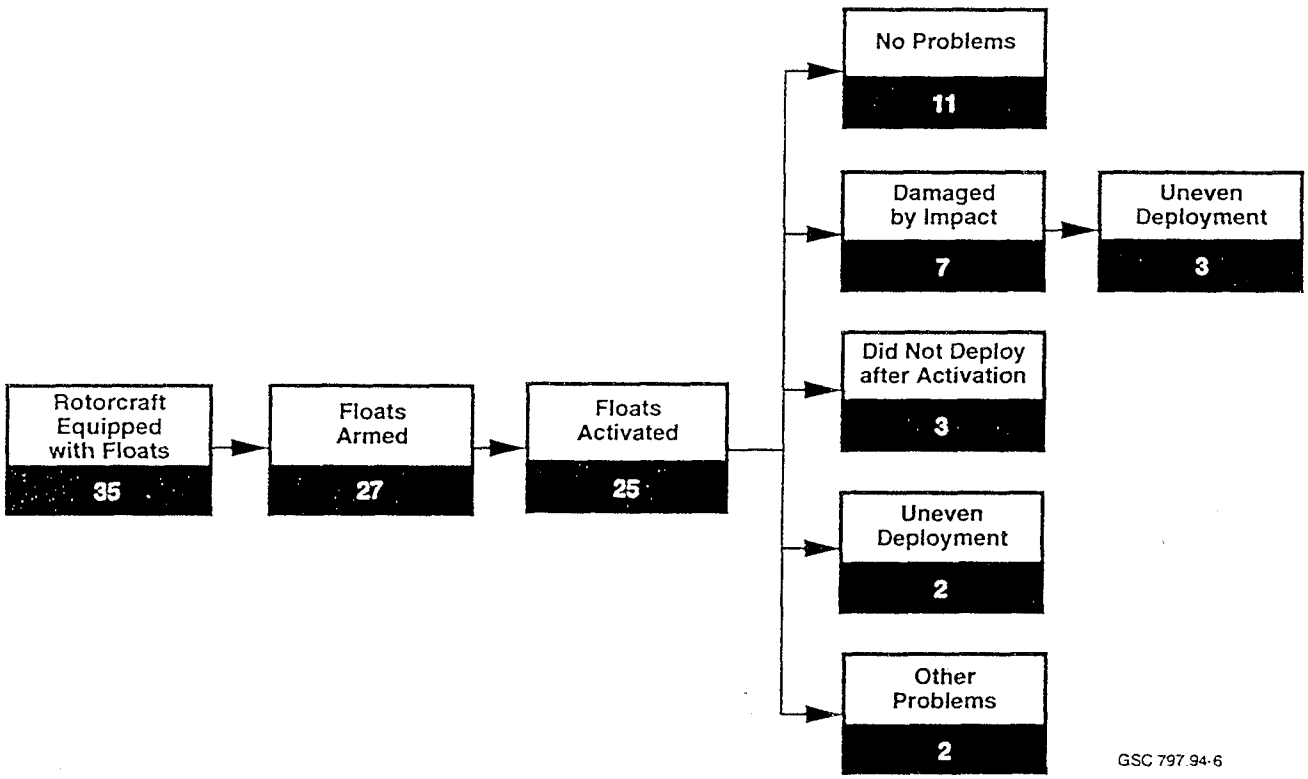


FIGURE 10. SUMMARY OF ROTORCRAFT DEPLOYABLE FLOAT PROBLEMS

The major problem associated with the floats which were activated was damage caused by the impact. Seven of the 14 float problems were caused by impact damage. This damage ranged from rupture of one or more floats to complete separation from the rotorcraft. Five of six cases in which the floats were damaged by impact, and the time of activation was known, involved floats that were activated before impact and was most likely a result of high water entry forces. Flotation systems which do not deploy until after impact are not subjected to these forces, resulting in fewer cases of float system damage caused by impact. In addition to impact damage, three rotorcraft had floats that did not inflate after activation. Five float systems did not deploy evenly, but three of these were damaged by impact.

Figure 11 shows float survivability relative to when the floats were inflated during the impact sequence. The floats survived impacts more severe than those defined by the current FAA guidelines. This shows that a difference exists between the capabilities of floats in surviving impacts and the FAA regulations. If the rotorcraft and the floats are being designed to survive more severe impacts, similar efforts are required to address postimpact hazards such as occupants trapped in the rotorcraft, drowning, and exposure to extreme water temperatures.

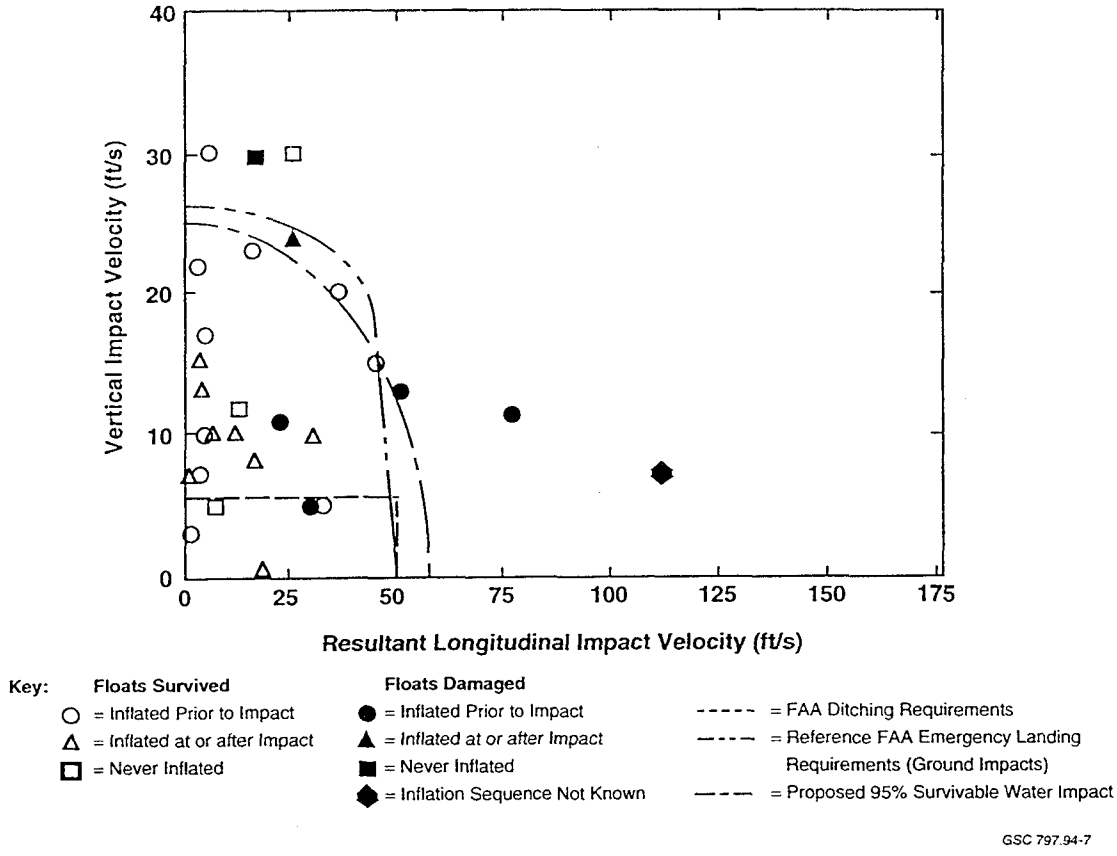


FIGURE 11. ROTORCRAFT DEPLOYABLE FLOAT IMPACT SURVIVABILITY

Of the 60 accidents, only 4 had impact conditions within those specified by the FAA for ditchings. In the remaining 56 cases, a total of 32 survivable or partially survivable accidents was identified in which the rotorcraft was equipped with emergency flotation systems. The following results were observed for these cases:

a. Thirteen of the 32 float-equipped rotorcraft involved in nonditching water impacts had floats that were activated and survived water impact.

b. Eight of the 13 rotorcraft with floats that survived impact overturned immediately.

The data suggest that under the common water impact conditions, the floats often do not keep the rotorcraft upright or afloat for occupant egress. In 11 cases where the rotorcraft sank, occupant drownings occurred. It would seem that an inverted floating rotorcraft is safer than one that is sinking, because by remaining near the water surface the chance of successful egress should be increased.

For the three cases that did not inflate after activation, one had the activation electrical wiring damaged by the impact; the reason for the other two floats not inflating is unknown. One rotorcraft was known not to have a backup activation system installed. FAA guidelines recommend a mechanical backup system for electrical activation systems, but also allow backup electrical systems provided they are shown to be independent and of high reliability. It is not known if the three cases in question had backup systems installed or if they were activated. Installation of a backup inflation system is desirable.

Five rotorcraft suffered from uneven float deployment; three of these had damaged floats. Specific information on the type and extent of float bag damage was not available for these cases. FAA guidelines recommend use of either a single inflation agent container or use of a multiple container system interconnected to help prevent uneven deployment. If a system is interconnected, the gas will follow the path of least resistance. If a float cell chamber is severely damaged (ripped), then more flow will be diverted to that float causing less inflation for the intact float chambers. The float inflation systems, however, operate under high pressure, and high flow velocities are developed in the distribution lines. Therefore, most of the flow resistance is in the flow distribution lines and not in the resistance of inflating the bag. The amount of gas lost to a ripped chamber during inflation is less than intuitively thought. Therefore, it is important to design the flow distributing lines with equal resistance and/or use flow distributing valves to ensure equal float deployment, even with a cell ruptured.

4.2 SUMMARY OF ACCIDENT/INCIDENT DATA SYSTEM REVIEW.

A previous review of the FAA's Accident/Incident Data System (AIDS) examined the records for 1982 to 1989. Thirty-seven rotorcraft ditching accidents/incidents were identified that were not included in the NTSB sample for the same years. The current study extended the AIDS review to include all water impact and ditching occurrences between 1982 and 1993, and resulted in 109 records. The performance summary of these 109 accident/incidents is given in table 10.

TABLE 10. AIDS ROTORCRAFT DITCHING DATA SUMMARY: 1982–1993

AIDS Number	Performance Category	Occupants	Fatalities	Injuries	Phase of Flight	Auto-rotation	Over-turn	Sank
890704	I	1	0	0	Landing	Y	N	N
880818	I	3	0	0	Cruise	Y	N	N
881117	I	3	0	3	Landing	Y[1]	N	Y[2]
881215	I	4	0	2	Landing	Y	N	N
871015	I	1	0	0	Landing	Y	N	N
850426	II	8	2	1	Takeoff	N	N	N
870916	II	1	0	1	Takeoff	N	Y	Y
881110	II	4	0	4	Landing[3]	N	Y	N
821203	II	3	2	0	Landing	N	Y	Y
830610	II	4	2	2	Landing	N	Y	Y
870819	III	4	0	4	Takeoff	N	Y	N
860830	IV	1	0	0	Takeoff	N	N	N
870604	V	2	0	0	Cruise	N	N	N

96 records (88.1 percent): No floats mentioned
13 records (11.9 percent): Floats mentioned

[1] Hard autorotation float landing.
[2] Sank during recovery effort.
[3] Hovering at 20 feet above water for photography flight.

Table 10 shows 13 accidents that specifically mentioned the use of an emergency flotation system. The performance category shown was included to describe the flotation system performance in each of the 13 accidents/incidents. Based on these records, five performance categories were created and are defined in table 11. Note that the AIDS database does not provide enough data for the reconstruction of the impact conditions, and therefore it was not possible to categorize these incidents as either ditchings or water impacts.

TABLE 11. FLOTATION PERFORMANCE CATEGORIES

Category	Float Performance	Incidents
I	Floats deployed successfully	5
II	Floats were not armed	5
III	Floats were activated too late	1
IV	Floats would not deploy (malfunction)	1
V	Floats deployed unintentionally (malfunction)	1

Five of these 13 accidents/incidents involved successful deployment of the floats and resulted in a safe landing. In all five of these incidents, the rotorcraft were autorotated to the water surface and did not overturn after impact. The float systems were not armed in five additional accidents/incidents. This was primarily because of a lack of time to arm the systems. As was noted previously, pilots complained of having insufficient time to activate the floats during an emergency landing. Table 10 shows that all five accidents in this category (Category II) took place during the takeoff or landing phases of flight. During these phases of flight, the pilot has even less altitude, and therefore less time, in which to perform the emergency landing procedures. Although the floats were deployed in the single Category III accident/incident, it was not in time for the floats to be effective. This event occurred during the takeoff phase of flight. This may have contributed to the lack of time needed to activate the floats. The remaining two accidents/incidents involved flotation system malfunctions: one in which the pilot was unable to get the floats to deploy, and one in which the floats deployed unintentionally because of an electrical short in a wire bundle. A summary of the occupant injuries associated with each of the five float performance categories is given in table 12.

TABLE 12. AIDS DATA INJURY SUMMARY

Category	Incidents	Total On Board	Total Fatalities	Total Injuries
I	5	12	0	5
II	5	20	6	8
III	1	4	0	4
IV	1	1	0	0
V	1	2	0	0
Total	13	39	6	17

The five Category I successful float performances resulted in injuries to 5 of the 12 occupants but no fatalities. The Category II accidents/incidents in which the floats were not armed resulted in 6 fatalities and 8 injuries of the 20 total occupants on board. The single Category III accident/incident in which the float was not deployed in time resulted in all four occupants being injured. The final two cases involving float system malfunctions did not result in any occupant injuries.

Categories I and V represent the events in which the floats were fully deployed at impact, and Categories II, III, and IV represent the events in which the floats were not deployed at impact. Table 13 summarizes the injury and rotorcraft overturning data for these lumped categories for the purpose of determining the effect of the float deployment on occupant injury levels. Those accidents/incidents in which the floats were deployed, whether by intent or malfunction, resulted in no fatalities and a total of five injuries. When the floats were not deployed, six fatalities and 12 injuries occurred.

The six accident/incidents in which the floats were deployed resulted in no rotorcraft overturnings and one rotorcraft sinking. This sinking occurred during the recovery effort and was not directly attributed to the water impact. The remaining accident/incidents in which the floats did not deploy resulted in five rotorcraft overturnings and three rotorcraft being sunk.

TABLE 13. INJURY AND ROTORCRAFT OVERTURNING SUMMARY BY FLOAT DEPLOYMENT

Deployment	Incidents	On Board	Fatalities (Rate %)	Injuries (Rate %)	Overturned	Sank
Deployed	6	14	0 (0)	5 (35.7)	0	1*
Not Deployed	7	25	6 (24.0)	12 (48.0)	5	3
Total	13	39	6 (15.4)	17 (43.6)	5	4

These data indicate that emergency float systems, when successfully deployed, reduce the potential for occupant injuries and aid in maintaining the stability of the rotorcraft. This sample resulted in a 24 percent decrease in fatality rate and 12.3 percent decrease in occupant injury rate upon successful deployment of the emergency floats. It appears the main reason for the failure of float deployment is a lack of time for the pilot to arm and activate the system, which may be because most of those accidents occurred during the takeoff and landing phases of flight.

4.3 SUMMARY OF SDR DATA.

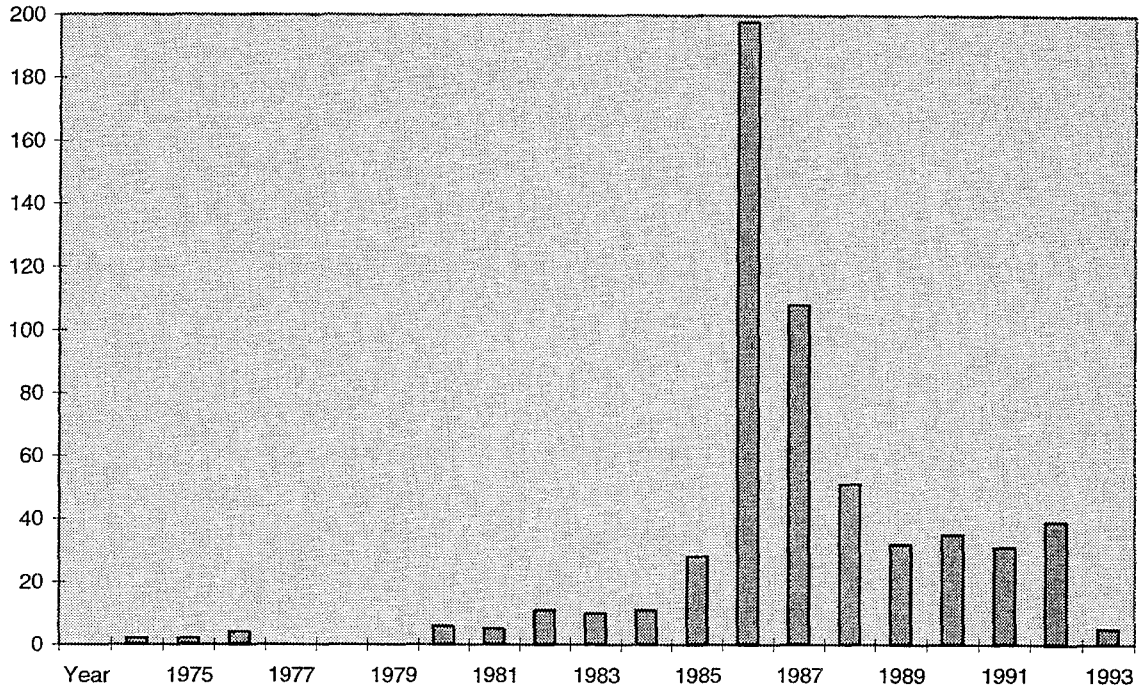
SDR data were collected and analyzed to assess the performance of float systems subjected to less severe (nonaccident) operating conditions. The intent of this analysis was to address the bias in previous flotation performance analyses which looked at only accident data and to identify potential problems which may exist in current civilian flotation systems.

SDR data were available for 1974 to 1993. Two search parameters were used to limit the sample used in this analysis. The first parameter limited the search to only those service difficulty reports involving rotorcraft. The second parameter refined the search to those rotary wing service difficulty reports that were included in the Emergency Flotation Section of the Air Transport Association (ATA) Component Table. The data were analyzed with respect to the year, phase of flight, component involved, cause of the "difficulty," and finally rotorcraft weight class. The results of the analysis are discussed below.

4.3.1 Yearly Distribution of Flotation System Service Difficulties.

The distribution of float-related service difficulties by year is shown in figure 12. These data show that the reported service difficulties were concentrated in the late 1980s and early 1990s. This rise in the number of reported difficulties may reflect the increased use of flotation systems during this time period. The subsequent drop in the number of reports could be attributed to improvements in these systems after service experience.

The number of rotorcraft flotation system service difficulties in this period relative to the number of total rotorcraft service difficulties provides some perspective on flotation system problems. A total of 578 rotorcraft flotation system service difficulties were identified for 1974 to 1993. This represents 1.3 percent of the total number of rotorcraft SDRs (44,333) for the same time period, therefore flotation represents a relatively small percentage of total rotorcraft service difficulties.



Total = 578

FIGURE 12. DISTRIBUTION OF FLOAT SDRs BY YEAR

4.3.2 Distribution of Service Difficulties by Phase of Operation.

Approximately 97 percent of the SDRs identified in this report occurred during inspections. Table 14 shows the distribution of SDRs that occurred during other phases of operation.

TABLE 14. SDRs BY PHASE OF OPERATION

Phase of Operation	Service Difficulties	
Landing	11	(1.9%)
Cruise	4	(0.70%)
Takeoff	2	(0.35%)
Taxi	2	(0.35%)
Total	19	

4.3.3 Distribution of Service Difficulties by Component Type.

Knowledge of the specific component which resulted in the service difficulty is useful as it could be used to identify those areas of the float system design which may need improvement. There were a total of 28 different components that were recorded under the PARTNAME field in the data sample. Table 15 lists the major components involved with these service difficulties.

TABLE 15. DISTRIBUTION OF SDRs BY COMPONENT TYPE

Component	SDRs	Percent of Total Flotation System SDRs
Float Bag	263	45.5
Valve	139	24.0
Gauge	49	8.5
Fittings	44	7.5
Others	83	14.5
Total	578	100.0

The predominant components which resulted in service difficulties were Float Bag, Valve, Gauge, and Fitting, which together accounted for 85.6 percent of the 578 SDRs in the data sample. Figure 13 shows the distribution of these component difficulties by year for the years 1974 to 1993. The component distributions rose abruptly in 1986 and rapidly dropped off thereafter. The "Float Bag" distribution also shows that the number reported service difficulties rose again in 1991 and 1992. Also, "Valves" exhibited a jump in the number of service difficulties reported in 1990. It is unknown whether this represents a reporting phenomenon or a service difficulty trend.

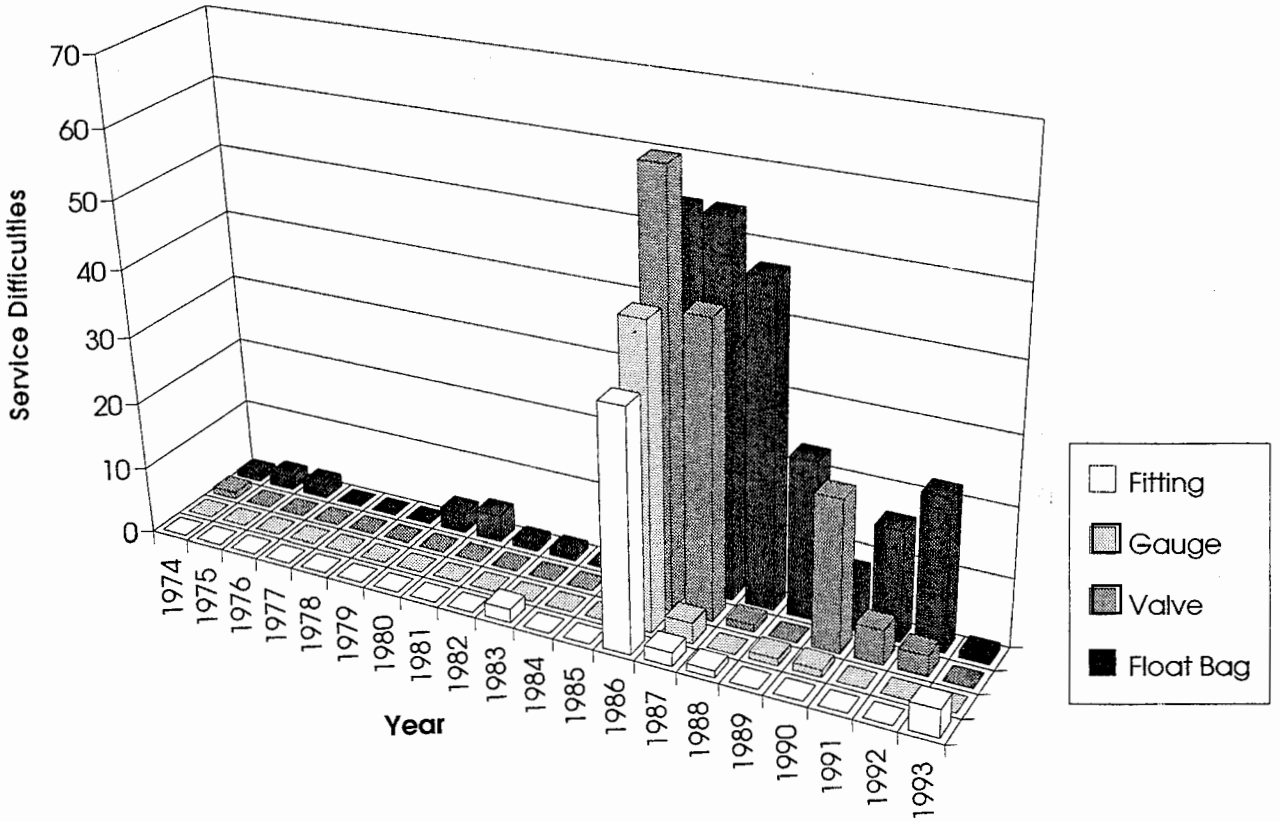


FIGURE 13. DISTRIBUTION OF "FLOAT BAG," "VALVE," "GAUGE," AND "FITTING" DIFFICULTIES BY YEAR

4.3.4 Distribution of Service Difficulties by Part Condition.

Identifying the part condition that led to the difficulty gives insight into specific problem areas for each of the components involved. This analysis is concerned with the part conditions of the four major components discussed. A listing of the part conditions associated with the Float Bag, Valve, Gauge, and Fitting are given in tables 16 through 20.

TABLE 16. FLOAT BAG PART CONDITIONS

Condition	SDRs	Percent of Float Bag SDRs
Leak	137	52.1
Rupture	32	12.2
Torn	16	6.1
Blistered	14	5.3
Others	64	24.3
Total	263	100.0

There were 28 part conditions associated with the float bag component. The predominant conditions are listed in table 16. The most common condition was float bag leaks, which accounted for 52.1 percent of the float bag service difficulties. Thirty-two service difficulties (12.2 percent) were categorized as ruptured, which is a compilation of those float bags which either burst, ruptured, or exploded. Float bags which were torn, ripped, punctured, or had a hole were put into the torn category. There were 16 such difficulties identified (6.1 percent). The final major difficulty was blistering, accounting for 14 (5.3 percent) of the float bag SDRs.

Table 17 shows the most common part conditions associated with the valve component. The leading condition in this case is corrosion, accounting for 84 (60.4 percent) of the 139 valve SDRs. Twenty (14.4 percent) of the SDRs were caused by time change valves that were out of date. These SDRs are not of immediate concern; as they did not involve a component failure. The defective category is a compilation of conditions representing general valve malfunctions. There were 14 cases of defective valves, representing 10.1 percent of the valve SDRs. Cracked valves were reported six times and accounted for 4.3 percent of the valve SDRs.

TABLE 17. VALVE PART CONDITIONS

Condition	SDRs	Percent of Total Valve SDRs
Corroded	84	60.4
Out of Date	20	14.4
Defective	14	10.1
Cracked	6	4.3
Others	15	10.8
Total	139	100.0

Corrosion was the leading cause of gauge and fitting service difficulties as well, accounting for 87.8 percent and 95.5 percent of the total gauge and fitting SDRs, respectively. The data for gauge and fitting part conditions are shown in tables 18 and 19, respectively.

TABLE 18. GAUGE PART CONDITIONS

Condition	SDRs	Percent of Gauge SDRs
Corroded	43	87.8
Water	2	4.1
Reads low	2	4.1
Failed	1	2.0
Defective	1	2.0
Total	49	100.0

TABLE 19. FITTING PART CONDITIONS

Condition	SDRs	Percent of Fitting SDRs
Corroded	42	95.5
Loose	2	4.5
Total	44	100.0

Table 20 gives the percentage of total SDRs in the data sample for each of the leading part conditions. The 4 parts and their conditions noted in table 20 accounted for approximately 53 percent of the SDRs reported for rotorcraft flotation systems. Float bag leaks occurred in 23.7 percent of the entire data sample, and corrosion of the valve, gauge, or fitting occurred in 26.2 percent of the data sample.

TABLE 20. LEADING PART CONDITIONS

Component	Part Condition	SDRs	Percent of Total SDRs
Float Bag	Leaks	137	23.7
Valve	Corroded	84	14.5
Gauge	Corroded	43	7.4
Fitting	Corroded	42	4.3
Total		306	52.9

4.3.5 Distribution of Service Difficulties by Weight Class.

Examining the distribution of service difficulties by aircraft weight class is useful as it can verify that the data sample is representative of the overall aircraft fleet by weight and size. Table 21 presents the distribution of rotorcraft by weight class as of 1991, and the number of SDRs identified in each weight class for 1974 to 1993. This allows an SDR rate to be calculated, defined as the ratio of the number of SDRs identified per rotorcraft for each weight class. The weight classes were defined in section 2.4.

TABLE 21. SDR RATES BY ROTORCRAFT WEIGHT CLASS

	A	B	C	D	Total
Rotorcraft	3,113	4,977	1,018	313	9,421
SDRs	2	431	134	11	578
SDR Rate (x 1,000)	0.64	86.6	131.6	35.1	61.4

Weight class B and C were the predominant weight classes in terms of total SDRs, representing 98 percent of all SDRs reported in 1992. The distribution of SDRs per weight class is representative of the overall U.S. civil rotorcraft fleet. It is expected that weight classes B and C would have the highest SDR rates, as the emergency flotation systems are most commonly associated with these weight classes. The SDR rate of weight class B may be slightly less than that of weight class C because of the relative simplicity of the skid mounted flotation systems. The complexity of the weight class C flotation systems, which are typically fuselage mounted, may be contributed to the higher number of service difficulties.

4.3.6 In-Flight Service Difficulties.

As mentioned, 97 percent of the SDRs in these data resulted from problems detected during inspection. Most of these difficulties were corrected immediately and did not present any hazard to the rotorcraft or personnel. There were 19 SDRs in the data sample that did not occur during inspection. Two of these occurred during taxi, and the remaining 17 occurred during the takeoff, cruise, and landing phases of flight. A brief investigation of these 17 service difficulties was performed to compare them to the data previously obtained from the NTSB and AIDS sources. Table 22 presents the relevant data associated with these more serious SDR events.

Table 22 shows that 6 of the 17 events involved the float or float bag. Three of these events occurred during a single rotorcraft landing, where three of the floats failed upon impact.

Four SDR events involved a float bag which failed to inflate. In one incident, the cause was attributed to two broken wires. Two of the incidents in which the floats failed to inflate resulted in the aircraft rolling over on impact and sinking.

Three SDRs involved the failure of the float cover. Two of the three events occurred during the cruise phase of flight, resulting in one float bag being deployed.

Two additional incidents involved the floats being deployed inadvertently during cruise. Float covers should be designed to remain attached during all expected flight conditions. The inadvertent deployment of floats during conditions of high velocity may result in the rotorcraft becoming uncontrollable.

The remaining five SDR events involved failure of the landing gear cross tube or metering pin during landing and are not directly attributed to a failure of the flotation system.

It is difficult to assess the success of the floats in these 17 cases as it is not known if the impact conditions were within the FAA ditching envelope. There are few service difficulties associated with in-flight failures of the float systems (2.1 percent in this study).

TABLE 22. NONINSPECTION SDR EVENTS

SDR Number	Phase	Partname	Condition	Remarks
100675079	Cruise	Float Cover	Failed	Float bag cover came loose during flight allowing bag to deploy. Plastic retainer strip not adequate to retain.
811222069*	Landing	Float	Torn	Float separated from skid during landing.
811222070*	Landing	Float	Torn	Float separated from skid during landing.
811222071*	Landing	Float	Torn	Float separated from skid during landing.
820216041	Cruise	Float	Inflated	Emergency float inflated at 90 kts.
820723095	Landing	Cross Tube	Broken	Rear cross tube broke on landing on offshore platform.
820915038	Landing	Cross Tube	Cracked	Aft cross tube failed during landing.
821006033	Landing	Arch	Broke	Welded joint of arch at attach fitting to skid broke.
840402055	Landing	Cross Tube	Broke	Aircraft settled to side during landing and broke r/h float aft cross tube.
840510022	Landing	Metering Pin	Broke	Left main landing gear failed to extend. Found metering pin broken.
861001046	Landing	Cap	Separated	Cap separated from valve during emergency landing. Floats did not fully inflate and aircraft rolled over in water.
861008013	Takeoff	Float	Did not inflate	Floats did not inflate after engine failure during takeoff. Aircraft rolled over and sank.
890621045	Takeoff	Float Cover	Came Loose	Float cover began opening up because of snaps coming unsnapped.
890629141	Landing	Squib	Failed to fire	Pilot activated float, left float failed to inflate.
890713159	Cruise	Float Cover	Separated	Float cover departed aircraft, exposing the float bag.
890810003	Landing	Wire	Broken	Floats failed to deploy during autorotation after power loss. Two wires found broken at solder connection.
900523199	Cruise	Float Bag	Hole	Floats inadvertently activated by pilot. Floats inflated at flight idle. Compartment deflated within moments of activation.

* These three float failures were reported for the same rotorcraft incident.

5. PROPOSED FLOTATION SYSTEM IMPROVEMENTS.

This section provides suggested improvements for the flotation problems identified in section 4. These suggested improvements are design-related as well as possible regulatory updates. Examples of upgraded float configurations are provided for two representative civil rotorcraft. A concept for enhancing the current arming and activation systems for rotorcraft float systems is presented. In addition, proposed improvements to individual float system components are discussed.

5.1 METHOD OF TURNING A CAPSIZED ROTORCRAFT.

As previously discussed, it is very difficult to prevent a rotorcraft from overturning after a water impact. An additional set of deployable floats can be placed near the top of the rotorcraft that would then be inflated after the aircraft is inverted in the water. The rotorcraft would then, depending on the center of gravity of the specific configuration, be turned on its side or come to rest floating inverted. A survivable airspace would then be maintained for any occupants still on board until egress could be accomplished.

Two examples are presented showing the feasibility of placing air bags on the rotorcraft for this function. One case study includes a typical Part 27 rotorcraft with skid-mounted main floats, and the other case is a typical Part 29 rotorcraft with fuselage-mounted main floats.

Figure 14 shows the part 27 rotorcraft with standard skid-mounted deployable floats. The upright and inverted floating positions are also shown. For this helicopter, the main floats provide 160 percent buoyancy of the maximum GTOW.

Figure 15 shows a possible location of two deployable floats that will either place the rotorcraft on its side or cause it to float inverted. The upper floats are drawn to relative scale and are sized to provide 125 percent GTOW buoyancy. The floats have been located so that they will not block occupant egress when inflated.

Figure 16 shows the Part 29 rotorcraft with standard fuselage-mounted deployable floats. The main floats provide 105 percent GTOW buoyancy and the fuselage provides 35 percent.

Figure 17 shows a possible location for the two upper deployable floats. It was more difficult to prevent interference with occupant egress with this rotorcraft because of the smaller relative space between the top of the doors and the main rotor. Thus, the floats have been shaped with a large step just behind the aft doors. The upper floats are drawn to relative scale and have also been sized to provide 125 percent GTOW buoyancy.

For the supplemental floats to be effective, the main floats must be inflated, with each providing at least 50 percent of the buoyancy required to support the rotorcraft's weight. Otherwise, the rotorcraft will most likely end up floating upright with the cabin area underwater.

The supplemental floats must be designed so that inadvertent deployment is impossible. Deployment of these floats would block the engine(s) air intake, forcing an autorotation. To prevent this scenario, it is proposed that the floats can only be activated by water contact switches near the top of the rotorcraft, plus an aircraft rollover switch. Therefore, the floats would only be inflated if the rotorcraft rolls over and water contact is sensed. This circuit would also be tied into the proposed float arming system.

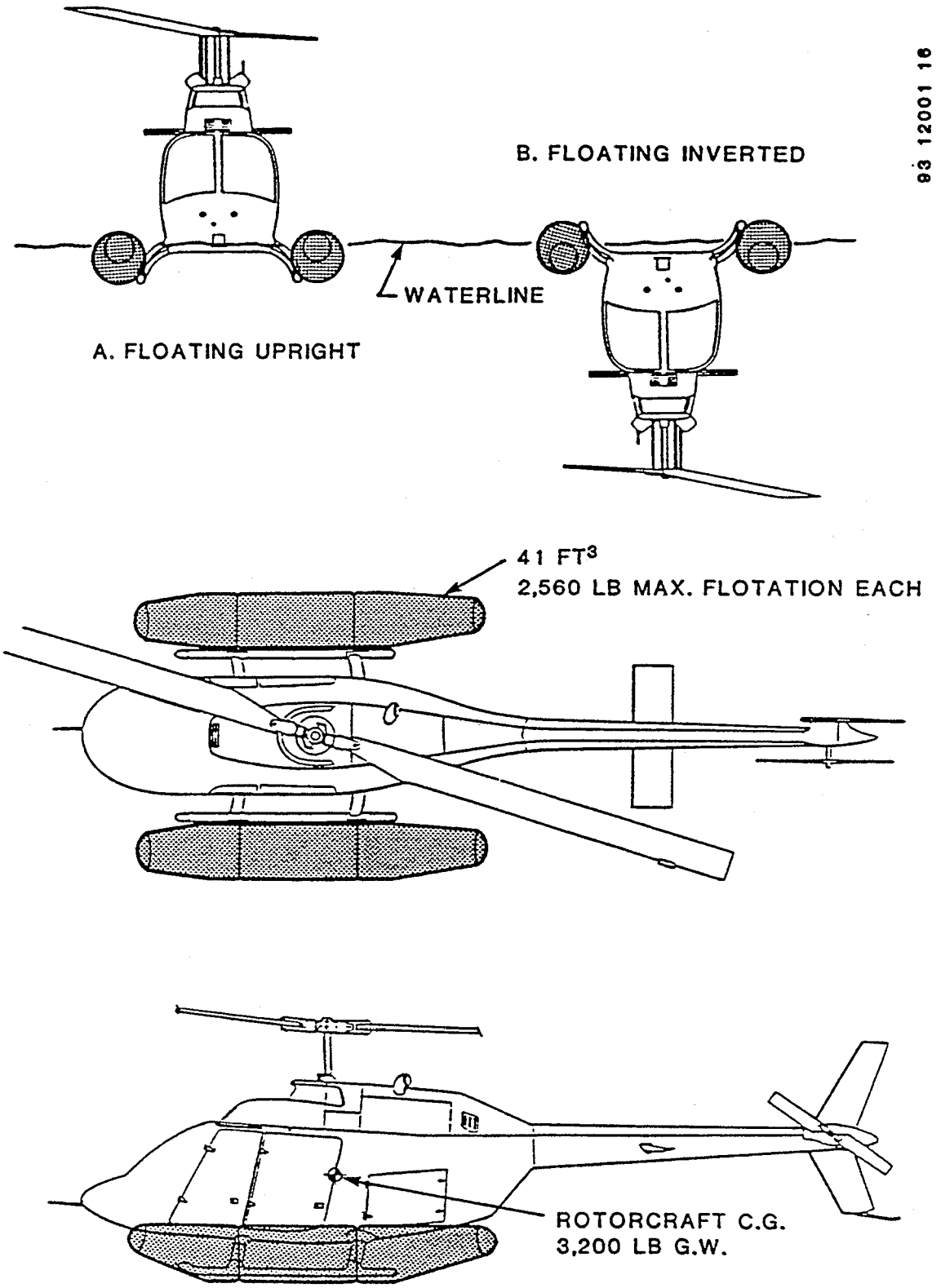


FIGURE 14. TYPICAL PART 27 ROTORCRAFT WITH SKID-MOUNTED POP-OUT FLOATS

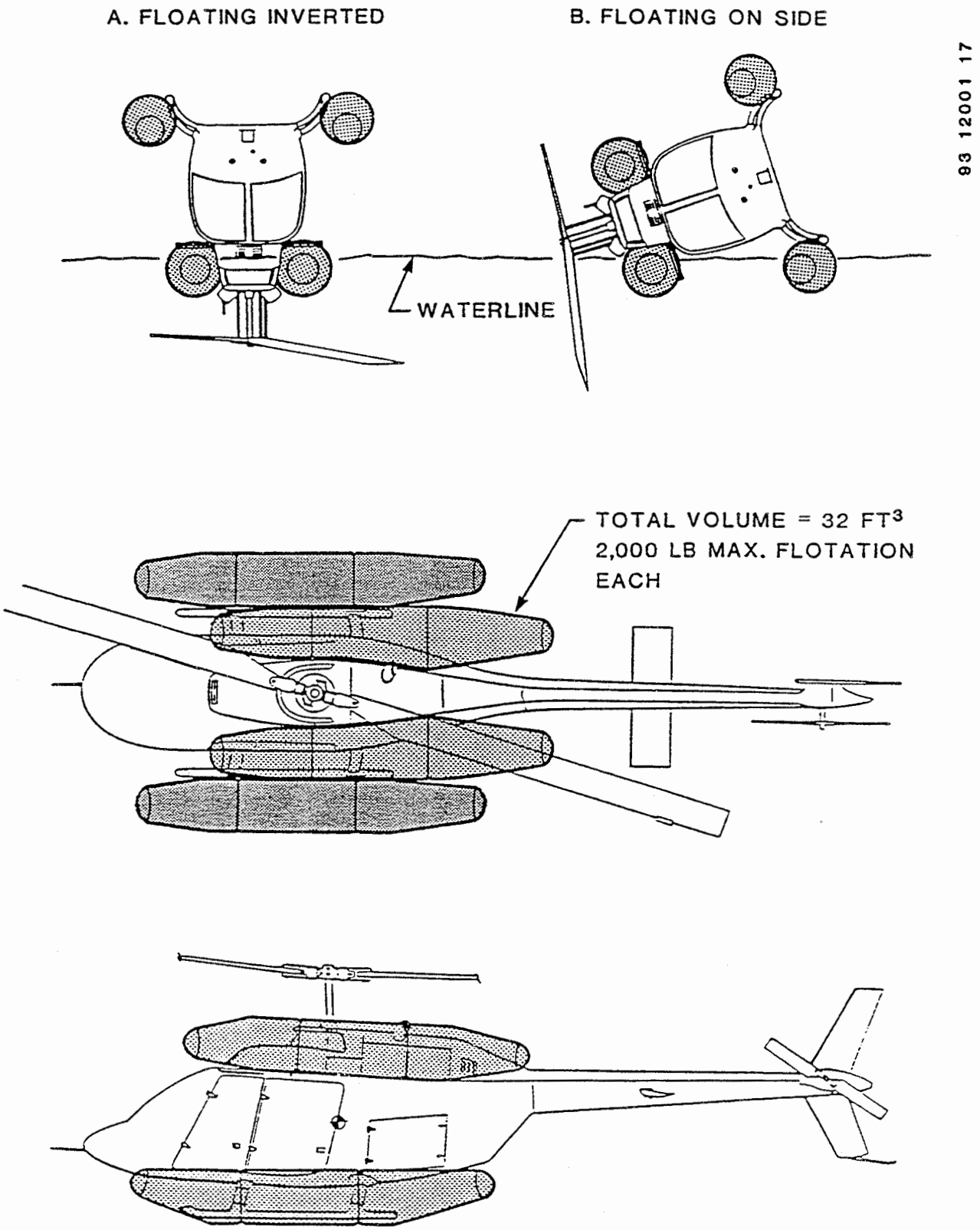


FIGURE 15. PROPOSED PART 27 ROTORCRAFT UPPER FUSELAGE-MOUNTED FLOATS

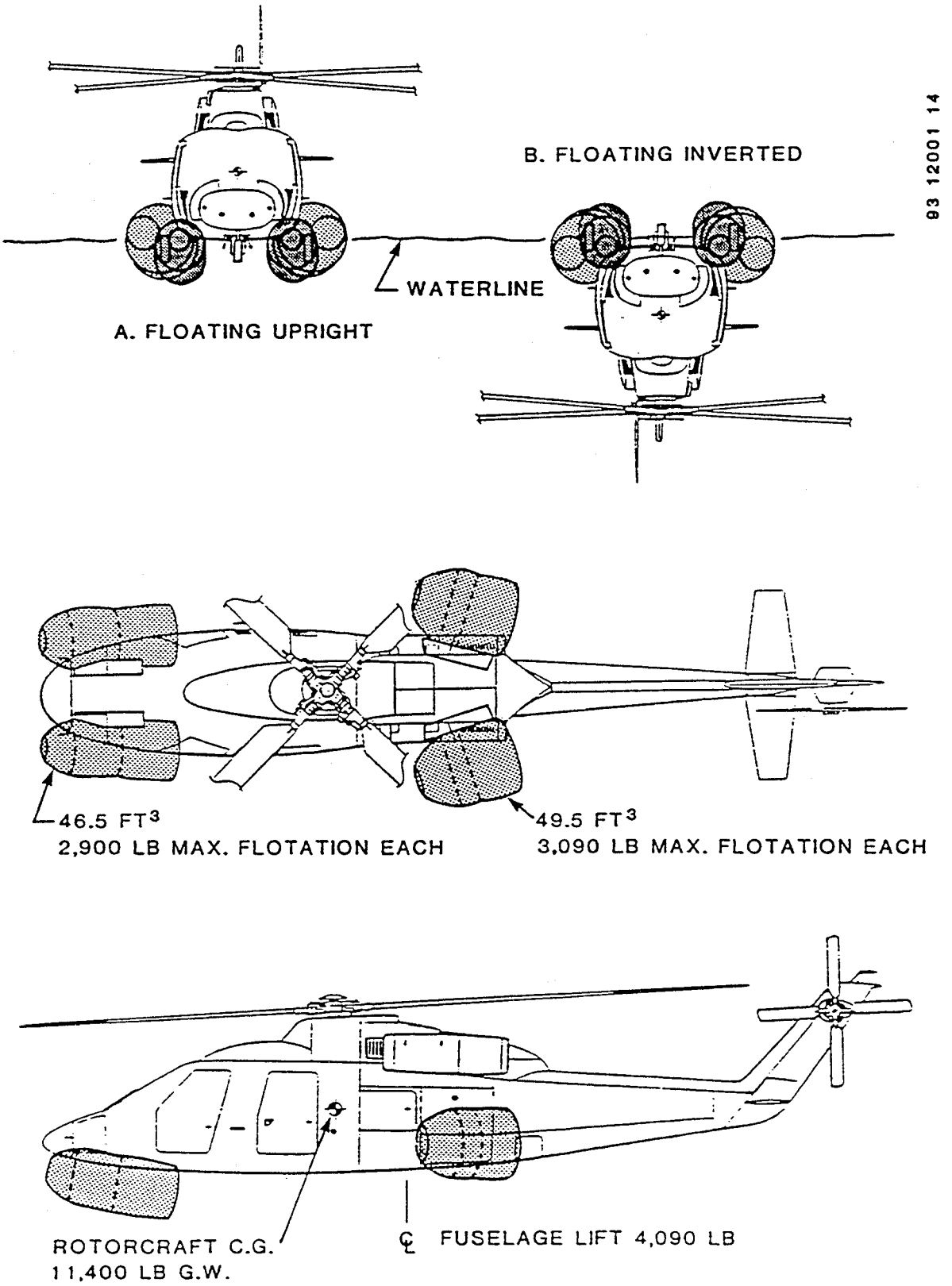


FIGURE 16. TYPICAL PART 29 ROTORCRAFT WITH SKID-MOUNTED POP-OUT FLOATS

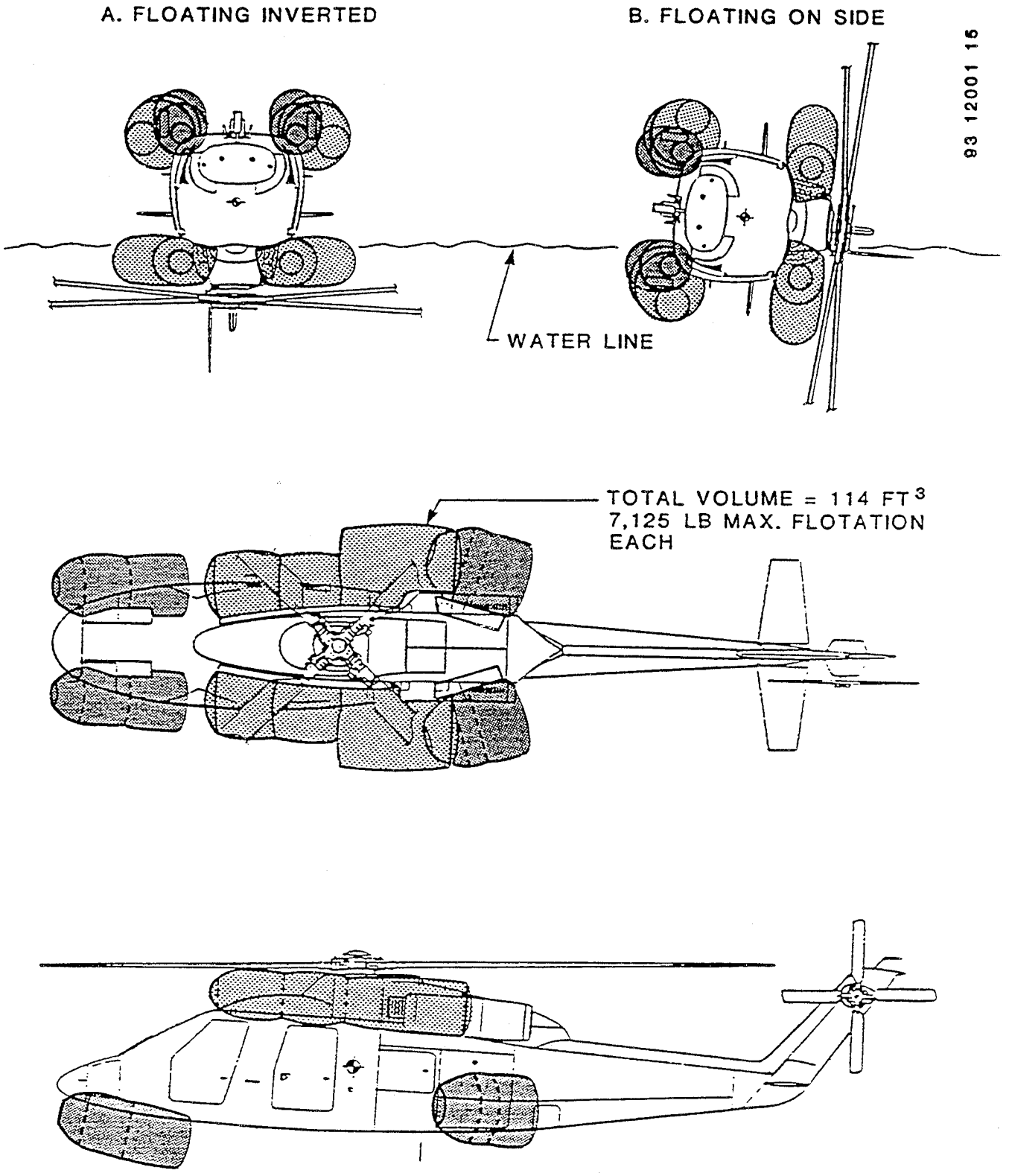


FIGURE 17. PROPOSED PART 29 ROTORCRAFT UPPER FUSELAGE-MOUNTED FLOATS

The cost and weight impact for adding the supplemental floats should be approximately the same as the primary float system. Research is needed to determine the feasibility of incorporating the supplemental floats. This may include detailed computer model analysis, scale model float tests, and even a full-scale prototype test. It is also difficult to quantify the end benefits of such a system. Perhaps the benefit could be partially demonstrated by conducting water inversion tests similar to the Navy's. For this test, the simulated rotorcraft would be raised and turned on its side after being submerged inverted.

5.2 IMPROVED FLOAT ACTIVATION SYSTEM.

Current systems use a manual safety switch to prevent inadvertent float deployment. The activation switch is armed only when the pilot is preparing to ditch. The data suggest that heavy pilot workload during emergency water landing conditions can prevent the float system from being armed. Therefore, another method for preventing inadvertent float deployment would be desirable.

The recommended solution to this problem is to provide an override function that senses the condition that makes float deployment unsafe. For example, if the airspeed must be below a certain value for safe float deployment, then the airspeed indicator would be used to send a bypass signal to the arming circuit. Figure 18 shows the flow diagram for typical existing float activation and the proposed activation diagram.

The proposed arming circuit would only be placed in the "off" position when ditching is not possible along the flight path. If ditching is possible along the flight path, the arming circuit would be placed in the "automatic" position. The floats would then inflate only when a safe deployment envelope is satisfied (based on sensor input) and when activated by the water impact switch. A third "manual" position is provided that provides the same function as the current arming circuit when in the "on" position. A separate backup system would also be provided for manual inflation.

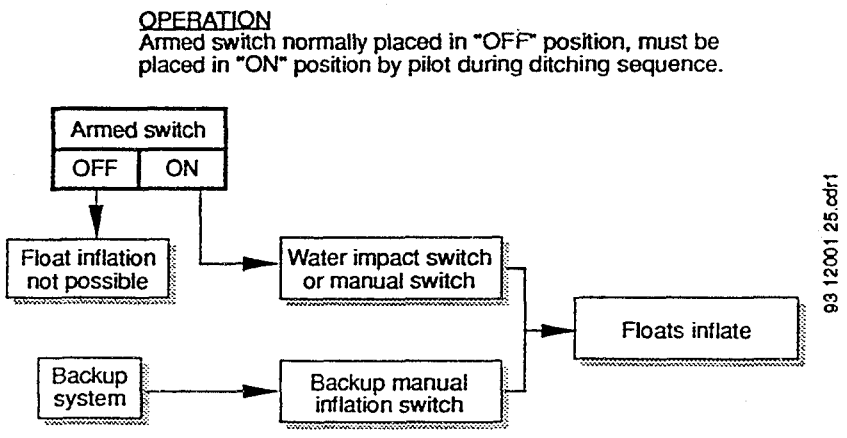
5.3 POTENTIAL REGULATION UPGRADES.

The most direct and probably most effective approach to solving the lack of water flotation equipment on some aircraft, a problem found in the review of service data, is to update the civil regulations. The following regulation upgrades are recommended:

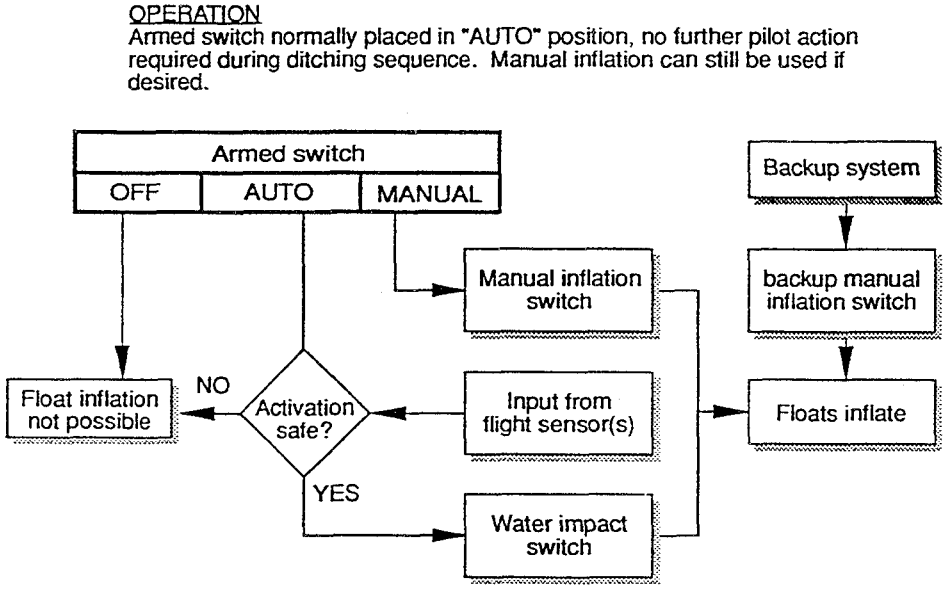
a. All single engine rotorcraft should be certified for ditching if operated overwater beyond autorotation distance from the nearest emergency landing area.

b. All multiengine rotorcraft should be certified for ditching if used for extended overwater operations.

c. Personal emergency flotation devices should be provided for all occupants if ditching can be considered along the flight path.



a. Typical current system



b. Proposed system

FIGURE 18. FLOAT ARMING AND ACTIVATION FLOW DIAGRAMS

Extended overwater operations are defined as more than 50 nautical miles from the nearest emergency landing area. As was mentioned in section 4.1.3, there were many instances of pilots choosing to put their rotorcraft down in water rather than on land. Therefore, even if there were an offshore landing pad greater than 50 nautical miles offshore, such a pad might not be used by pilots either. The data suggest that a pilot would prefer to ditch rather than attempt an emergency landing on an offshore structure.

The final recommended regulation upgrade is independent of distance from land and applies even if the flight path does not cross water.

5.4 GENERAL FLOAT DESIGN IMPROVEMENTS.

There are several recommended design and performance improvements based on the float problems discussed in section 4.1. The rotorcraft manufacturers also had several recommendations which are included. The following float system design improvements are recommended:

a. Design the floats to withstand water impact conditions and still maintain over 100 percent buoyancy.

b. Design the floats for balanced deployment (timing as well as volume), even with float damage.

c. Mandate use of a backup inflation activation system.

d. Use a standard, high visibility color for the float fabric with contrasting stripes to assist aircraft spotting during search and rescue missions.

e. Use tear-resistant fabric for the float construction.

f. Add hand holds on the floats to supplement personal flotation regardless of rotorcraft orientation.

Exits that could be jettisoned by a single control, perhaps at the pilot station, would be another method of aiding occupant egress in overturned rotorcraft. Such a feature would aid disoriented occupants who may otherwise be unable to open the exit door. This task becomes more difficult when occupants are suddenly upside down and submerged.

For the impact velocity requirements, it is recommended that the floats be designed to survive the 95th-percentile survivable water impact (25 ft/s vertical and 56 ft/s longitudinal). Existing floats have demonstrated survivability up to 30 ft/s vertical and 44 ft/s longitudinal impact velocities. Note that current structural ditching standards require up to 50 ft/s longitudinal impact velocity and at least 5 ft/s vertical.

The float system should demonstrate even float deployment with any single damaged float chamber. This demonstration should be done with the rotorcraft in the water as well as out of the water (unless floats cannot be deployed before water impact).

6. ANALYTICAL METHODS FOR ROTORCRAFT FLOTATION EVALUATION.

A review of current analytical methods was undertaken to identify those available that potentially could be used to simulate the complexities associated with rotorcraft flotation. Before reviewing the analytical methods, the complexities associated with analyzing helicopter flotation were categorized into four distinct problem areas. These are

a. buoyancy and stability,
b. wave action,

c. water entry, and
d. structural damage.

The problem areas that have received the most attention are buoyancy and stability because they are important in the sizing and location of the floats for a particular rotorcraft configuration. Beyond simple buoyancy and stability, the analytical treatment of water impact has been limited. The problem areas and the relevant analytical methods that were identified for each are described below. The potential for integrating these various methodologies is also discussed.

6.1 BUOYANCY AND STABILITY ANALYSES.

Nearly every helicopter manufacturer has prepared a computer program or programs to handle buoyancy and stability. The primary use of these codes is to conduct preliminary sizing and location of the helicopter floats. Available information indicates that these codes do not evaluate the ditching event, but rather evaluate an aircraft's ability to float upright following a ditching. Most of these codes assume a smooth water surface and primarily calculate the buoyancy provided by each cell of each float and apply appropriate reactions to the airframe.

The buoyant and floodable volumes in the airframe are also taken into account during partial airframe submersion. The codes use these data along with airframe mass properties to predict a static equilibrium condition (floating attitude). This permits the determination of the aircraft's water line relative to the exits. Similarly, some proprietary codes provide calculations of a range of roll and pitch that will not result in aircraft rollover. These codes are also used to assess the change in static equilibrium with one float cell not providing buoyancy (one cell out condition).

One such buoyancy and stability code is described in reference 7. The program can analyze up to three floats on each side of the aircraft. Each float may be represented by up to three geometric sections comprised of either a cone or cylinder. The geometry used as the basis for the analysis is shown in figure 19. The following equations were taken from reference 7.

The equation used to obtain the submerged volume of each float is:

$$V = \int_0^L A_x \, dx$$

The center of buoyancy of each float is calculated using the following equation:

$$CB = \frac{M}{V} = \frac{Moment}{Volume}$$

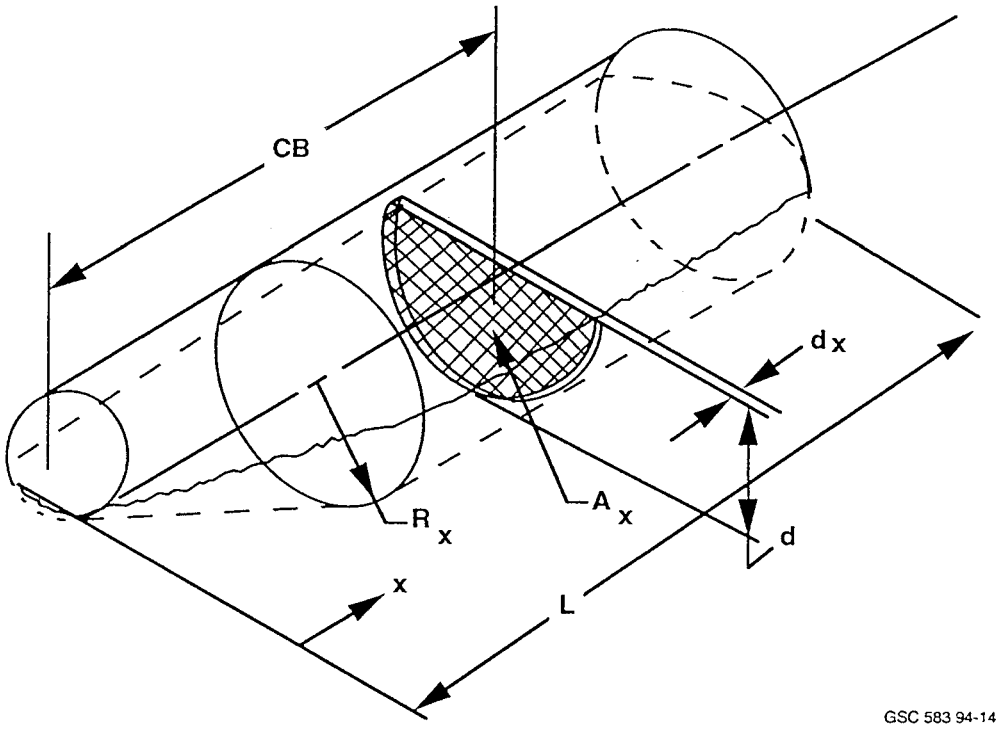


FIGURE 19. GEOMETRY OF TYPICAL FLOAT USED IN COMPUTER PROGRAM

The value for M in the x direction, M_x, is obtained from the following equation, as are M_y and M_z:

$$M_x = \int_0^L A_x \, x dx$$

To determine the static equilibrium position, the program varies the pitch and roll attitude of the aircraft, as well as the immersion depth, until the static equilibrium condition is satisfied. The data provided by the program include the following:

a. helicopter pitch attitude,
b. helicopter roll attitude,
c. water level,
d. center of buoyancy of each float,
e. center of buoyancy of float system,
f. buoyancy provided by each float, and
g. effect of one cell out.

For flotation conditions where the fuselage is partially submerged, the buoyant and flooded volumes in the fuselage must be determined and represented in the flotation analysis.

6.2 WAVE ACTION.

The effects of wave action on a ditching aircraft are typically evaluated through scale model testing (reference 7). Some helicopter manufacturers claim to have computer codes that simulate wave action; however, the information obtained regarding those codes was insufficient to assess their capabilities. Those codes are extensions of the buoyancy and stability analysis codes described previously to analyze buoyancy and stability of the flotation equipped aircraft on a nonsmooth water surface. The analyses evaluate the stability of the floating aircraft after a ditching, but do not evaluate the critical water entry phase of the ditching.

A well-documented wave action model is described in reference 24. The model, as described, is not specifically developed for helicopter flotation analysis, but rather for analysis of personal flotation devices. It is likely, however, that this wave action model could be applied to helicopter flotation. The wave action model (reference 24) is called the Wave Forces Analysis Capability (WAFAC) model. This model computes the effects of buoyancy, wave excitation, added mass, and drag forces on a system of linked bodies submerged in the water. The scheme for the buoyancy and wave excitation calculations assumes the immersed body to be an ellipsoid with a surface grid. The buoyancy and wave excitation forces are applied at the centers of the submerged grid elements. Sea states may be represented in two ways. The first is by superposition of up to ten regular waves. The second method is with a single wave with an amplitude equal to the "significant wave height," defined as the average of the highest third of the waves, and with a frequency based on statistical parameters of the Pierson-Moskovitz Spectrum for fully developed waves. The resultant force and moment acting on each ellipsoid is the vector sum of the individual force components.

Improvements to the WAFAC model were identified in reference 24. The first potential enhancement would be the variation of the added mass effects through the use of different coefficients in heave, sway, and surge. Secondly, the avoidance of the overestimation of water forces caused by overlapping ellipsoids should be addressed. This overestimation may result because the model treats each ellipsoid in the immersed body separately for the force calculations. Finally, the free water surface representation could be refined by using nonlinear theory.

6.3 WATER ENTRY.

Perhaps the largest void in the analytical treatment of helicopter flotation is the absence of methods for evaluating the water entry phase of a float-equipped helicopter in a ditching or water impact sequence. Ideally, such an analytical method would be able to evaluate the ditching or water impact of a helicopter with or without floats onto water surfaces of varying wave conditions. Such a method would be used to predict the forces developed on the airframe and the flotation system during the impact sequence.

A version of computer program KRASH for water impact offers a means to analyze the ditching or water impact of helicopters with or without floats. This program evaluates contact between the aircraft and water surface through the use of planing surface and hydrodynamic drag models (reference 23). The program currently considers the water surface to be smooth. The program calculates the depth of penetration, as well as the hydrodynamic forces and pressures, by means of

special hydrodynamic model elements. The hydrodynamic forces are then transmitted to the KRASH representation of the remainder of the airframe. Program KRASH models the aircraft structure with beams that connect lumped masses. Therefore, the program can determine the dynamic response of the airframe, including structural loads, in a ditching or water impact scenario. The program could be used so that floats, represented by hydrodynamic drag surfaces, could be modeled with a user-specified failure load. Such a model could be used to predict whether floats would remain intact for a given set of impact conditions and failure loads. More advanced representation of the floats and waves would require modification of the program.

The wave action model (WAFAC) could be applied to modeling the impact of a rotorcraft into water. The model has been shown to simulate a person impacting the water surface during, for example, a parachute recovery in the ocean following an ejection seat escape (reference 24). The velocities associated with this event are not unlike the velocities involved in a helicopter ditching. Therefore, it is believed that this model could be enhanced to provide a preliminary model capable of simulating a flotation-equipped helicopter ditching. The model assumes rigid buoyant segments for modeling the occupant's personal flotation device (PFD). Thus, the larger volume of the helicopter floats are a concern since distortion of the floats will be much greater than for the PFD. With significant enhancement, the model in reference 24 could be applied to the more severe water impact environment.

6.4 STRUCTURAL DAMAGE MODEL.

The purpose of a structural damage model in assessing flotation and ditching performance is to predict the behavior of the airframe and flotation system when subjected to the loads developed during the impact or water entry phase of the touchdown. Discussion of structural failure modes in water impacts, serves to highlight the phenomena to be modeled. Some of the failure modes described below are more representative of water impacts than controlled ditchings, but they illustrate the potential damage that may be incurred in emergency landings on the water.

The structural damage from water impact can be significantly different than that of a rigid ground impact. In the predominantly high vertical speed impact, there can be extensive deformation of the lower fuselage skin panels located between the frames and bulkheads. As the relatively low strength skin panels are torn away under the dynamic pressures associated with the hydrodynamic forces, structural hard points and major structural members are exposed. Bending failures in longitudinal members occur as a result of increased reaction loads produced as more of the structure is exposed to the water as the vehicle submerges. Bending and shear displacements of major structural members increase in relation to the submergence of the airframe. As a result, bending and shear failure of the aircraft floor structure is common in a predominantly vertical water impact.

In severe vertical water impacts, the water impingement on the floor structure can cause catastrophic loss of airframe integrity and the aircraft will totally submerge within a few minutes. High vertical descents that occur on rigid terrain, however, are usually characterized by large vertical displacement of vertical members with much less bending and shear deformation of the lower fuselage. Lower fuselage crush accounts for most energy dissipation in a rigid surface impact. Figure 20 shows the contrasting airframe deformation behavior of water and rigid ground impacts.

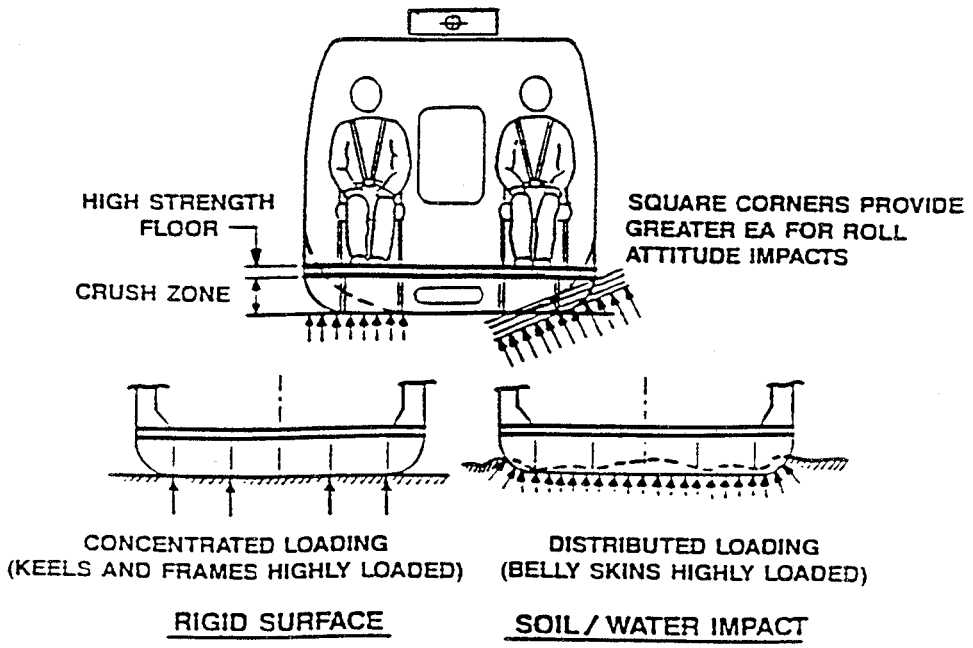


FIGURE 20. AIRFRAME DEFORMATION BEHAVIOR OF RIGID VERSUS NONRIGID GROUND IMPACTS

Where high forward speeds are involved in a water impact, the response of the structure can be highly dependent on the integrity of the lower fuselage and nose structure. If the lower fuselage panels and skins remain intact, i.e., they are not separated from frames and do not undergo large distortions, then the aircraft will slide or skid along the impact surface. As in an impact with a rigid terrain, the kinetic energy associated with the forward speed will be attenuated through friction. The longitudinal accelerations should be relatively low. Failure of lower fuselage panels will result in the exposure of vertical surfaces of frames and bulkheads, which offers a high drag resistance. This drag force increases as the area of exposure increases. When applied at the lower regions of the aircraft, it induces a nose-down pitching moment, which accentuates the nose-down attitude, which in turn increases drag on the forward structure. Aircraft nose-down pitching behavior is further accentuated by the immersion of exposed undercarriage structure, if it is not retracted. The drag loads resulting from water contact induce high longitudinal deceleration forces in the lower fuselage. These loads are opposed by inertia loads associated with the high mass items. Depending on the relative forces and pitching moments, aircraft nose-down rotation can result in a complete turnover of the vehicle, which would be unacceptable. As more structural surfaces come into contact with the water, the drag loads are again increased. The result of these rapidly increasing loads can be destruction of the cockpit and forward cabin areas.

Provided the models for the water entry phase can provide realistic load predictions, any number of currently available codes could predict the airframe structural damage resulting from a ditching or water impact. These include the program KRASH, already discussed above, as well as finite element analysis codes. Program KRASH is a computationally efficient tool suitable for

determining overall airframe response as well as indicating structural failures. Finite element programs are well suited for analysis of localized responses and damage to specific airframe components, although the global response of the entire airframe may also be modeled.

The computer program MacNeal-Schwendler Corporation (MSC)/DYTRAN is a general purpose, three-dimensional analysis tool for solving highly nonlinear, transient dynamic problems, including high-speed impact and transient fluid-structure interaction. It has been used to analyze such problems as bird strikes on aircraft, the blast response of structures, and the deployment of air bags in vehicle crashes. MSC/DYTRAN uses two processors in performing analyses. The Lagrangian processor uses conventional finite elements that have constant material mass. The finite element mesh follows the motion of the material. The Eulerian processor uses elements that are fixed in space. Material is permitted to flow from one element to the next. This model is well suited for simulation of fluids. The Lagrangian and Eulerian processors may be coupled to allow simulation of the interaction of fluids and structures. It appears that this program could be applied to the analysis of structure in ditchings and water impacts.

6.5 SUMMARY OF ANALYTICAL METHODS REVIEW.

Several analytical tools exist to simulate various aspects of the helicopter ditching and water impact environments. Unfortunately, the helicopter-specific tools cover only what is required to design a certifiable aircraft. Other analytical tools have recently been developed to simulate fuselage water impact, wave action, wave effects on aircraft stability, and wave effects on a buoyant device. It seems possible that this collection of analytical methods could be coupled or combined to produce a code or codes that could simulate the significant aspects of helicopter ditching and water impact. Available test data could be used to validate the codes. In addition, model or full-scale tests should be useful to validate these codes.

Some anticipated results that such an integrated code should provide can be described here. The analysis tool should be capable of calculating the range of water attitude conditions for flotation stability of the airframe under various aircraft weight, flooding, and float-cell conditions. Such analysis should also provide the water line position of the airframe relative to the exits for these various conditions. The analysis should be able to predict the time that the airframe will remain afloat given various loading, flooding, and float cell conditions. An especially important result would be the determination of the acceptable range of touchdown conditions for a successful ditching of the airframe. Finally, the analysis should be able to predict the structural behavior and any damage that may result from a given set of impact conditions.

Such a predictive tool, if it were successfully developed, would provide a means of examining the entire ditching or water impact sequence, from water entry to static equilibrium. It would provide a cost-effective means of predicting ditching performance and would be a complement to scale model and full-scale testing. It could be used by industry as both a design and potential certification tool.

7. CONCLUDING REMARKS.

Based on the review of rotorcraft emergency flotation systems the following statements can be made.

a. The NTSB accident data showed that occupants generally survived impact conditions more severe than those defined in the FAA ditching regulations. Drowning was found to be the leading cause of death, even in rotorcraft equipped with floats.

b. Rotorcraft, in both ditching and water impact scenarios, were found to overturn immediately upon impact. Overturns occurred to rotorcraft both with and without deployed floats. Rotorcraft overturning can trap would-be survivors beneath the surface of the water.

c. In addition to overturning, other design related float problems were identified. These problems include arming or activation methods, uneven deployment, and float separation on impact.

d. It was found that, although existing FAA regulations are generally being followed, gaps exist which allow for regular overwater operations without requiring the rotorcraft to be equipped with floats. A significant number of rotorcraft in the NTSB sample that impacted the water were not equipped with floats.

e. The accident data showed that emergency flotation equipment is generally not used by weight class A rotorcraft (less than 2,500 lbs gross weight). This may be caused by the weight penalties attendant to emergency float systems, which particularly impact smaller rotorcraft. Because of the popularity of these rotorcraft (they comprise 33 percent of the civil fleet) there may exist a need to develop emergency flotation systems that are more practical for use on these lighter weight aircraft.

f. The following solutions related to the design of rotorcraft flotation systems were suggested to increase occupant survivability during a water related accident or incident:

- Supplemental floats located near the top of the rotorcraft.
- Automatic float activation system which would not require pilot interaction.
- Standard, high-visibility color for the fabric with contrasting stripes to assist aircraft spotting during search and rescue missions.
- Tear-resistant fabric for the float construction.
- Hand holds on the floats to supplement personal flotation regardless of rotorcraft orientation.

g. The majority of flotation system service difficulties resulted from float bag leaks and corrosion of valves, gauges, and fittings detected during inspection. Weight class C rotorcraft (6,001 - 12,500 lbs Maximum Allowable Gross Weight [MAGW]) experienced the highest SDR rate of all four weight classes.

h. Current analytical tools only cover specific aspects of the overall water impact scenario. It is possible that several analytical methods could be combined to model the complete water impact scenario.

i. Proposed regulatory upgrades were suggested to address the gaps found in the current regulations.

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APPENDIX A—EMERGENCY FLOTATION SYSTEM RAW DATA

Model: Bell 206 — Rotorcraft Flotation Study : Flotation System Technical Survey

I. System Description

Floats: 6
Cells/Float: 1 (4 foward), 2 (2 year)
Vol./Float:
Float Material:
Mounting Location: skids: 4 small floats surround forw. x-tube; 2 lg. behind
Mode of Storage: aft x-tube folded & wrapped in cover ontop of skid.
Buoyancy: 160 % Gross Weight

bottles: 2
location of bottles: just aft of forward x-tube
bottle size: 51 in. x 9 in Diam. cylinder
type of gas: Nitrogen
bottle pressure: 3225 psig.
inflation time: < 5 sec.
infl. press. of floats: 2.25 psig.

time floats remain inflated (for different operating conditions):

Weight of System: 144.4 lbs.
Effect on CG:

II. System Operation

Arming Method: Switch mounted on overhead console

Activation Method: Trigger switch on collective stick

III. Operating Environment Parameters

Effect on flying quality: < 60 mph to inflate; < 80 mph after inflation; < 70 mph autorotation
Allowable landing speed:
Allowable landing attitude:
Operating temperature range:
Operating pressure range:
Water temperature:
Wave size:
Wind:
Permissable damage condition:

IV. Installation

Procedure: by operator as kit; once installed, quick removal and quick installation kits are available for temporary use of floats. Floats can be taken off and put back on in minutes without removing mounts.

V. Service Testing and Maintenance

Frequency of inspection: pre-flight and 180 day (500 hour)
Type of inspection: pre-flight: visual check only; 180 day: full inflation
Standard inspection tests:

Warning/Status indicators: 2 caution lights on caution panel; 1 for armed indicator, 1 for test of circuit continuity
Component Re-usability: Completely re-usable to 10 years of service. Can make minor repairs only after this point

VI. Method of Qualification/Certification

VII. Miscellaneous Comments

- Additional position lights on fuselage prevent blackout when floats are inflated.
- Can still use standard ground handling wheels when floats mounted.

Model: Bell 222/230 Rotorcraft Flotation Study : Flotation System Technical Survey

I. System Description

# Floats	4	# bottles	1
Cells/Float	2 (2 forward floats); 5 (2 wing floats)	location of bottles	Behind baggage compartment
Vol./Float		bottle size	
Float Material		type of gas	Nitrogen
Mounting Location		bottle pressure	2850 - 3100 psig.
Mode of Storage	Within hard plastic fairings attached to airframe	inflation time	6 seconds
Buoyancy	minimum 125%	infl. press. of floats	2.25 psig.

time floats remain inflated (for different operating conditions)

Weight of System 209 lbs., (skid), 223 lbs. (wheel) *non-removable portions weigh 45 lbs.

Effect on CG

II. System Operation

Arming Method: Pedestal mounted switch - required for any t/o or landing over water or when operations are within proximity to water

Activation Method: Must be armed with any 2 or 4 immersion switches submerged. Manual backup handle (covered by transparent spring-loaded plastic cover) can be pulled AFTER landing.

III. Operating Environment Parameters

Effect on flying quality: No airspeed penalty when stowed. Cannot be flown with floats inflated.

Allowable landing speed

Allowable landing attitude

Operating temperature range

Operating pressure range

Water temperature

Wave size	Sea State 6	All cells OK	Sea State 2	One cell deflated.
Wind	25 kts.		12 kts.	

Permissable damage condition

IV. Installation

Procedure: By operator.

V. Service Testing and Maintenance

Frequency of inspection: pre-flight and 180 day (500 hour)

Type of inspection: pre-flight: visual inspection only; 180 day: full inflation test

Standard inspection tests

Warning/Status indicators: "FLOATS ARM" on caution panel.

Component Re-usability: Completely re-usable to 10 years of service. At this point, any excessive difficulties lead to retirement.

VI. Method of Qualification/Certification

Scale model tests : 1/8 and 1/24 scale.

VII. Miscellaneous Comments

Mechanical backup shall not be activated in flight as it may cause rotorcraft to lose control.

Model: S-76

Rotorcraft Flotation Study : Flotation System Technical Survey

I. System Description

# Floats	4	# bottles	4
Cells/Float	2	location of bottles	Nose 2-under pilot & co-pilot seat; Aft 2 - i
Vol./Float	48.5 cu.ft (nose), 49.5 cu.ft. (main)	bottle size	490 cu.in. each
Float Material	Urethane coated nylon	type of gas	Helium or nitrogen
Mounting Location	fuselage - beside nose ldg. gear & inside MLG doors	bottle pressure	3000 psi
Mode of Storage	folded INSIDE fuselage	inflation time	< 5 sec. (3 sec. for sufficient buoyancy)
Buoyancy	153% (10,500 lb.) or 141% (11,400 lb.)	infl. press. of floats	0.75 - 3.5 psi (varies with temp.)

time floats remain inflated (for different operating conditions)

Weight of System 114 lb.

Effect on CG CG @ FS 186

II. System Operation

Arming Method Electrical arming switch on center console for pilot.

Activation Method Firing switch on cyclic stick: electrical activation fires protechnic charged in each bottle manifold, thus puncturing diaphrams in the gas flow through the lines to inflate the floats.

III. Operating Environment Parameters

Effect on flying quality < 75 kts.; all other performance unaffected (while stowed)

Allowable landing speed < 33 kts.

Allowable landing attitude

Operating temperature range

Operating pressure range

Water temperature

Wave size 1:10 steepness (height to length) ratio; ditching safe up to Sea State 4.

Wind

Permissable damage condition Equal distribution of gas if one bottle fails to fire; redundant wiring.

IV. Installation

Procedure A/C manufacturer can install or operator in field as a kit.

V. Service Testing and Maintenance

Frequency of inspection pre-flight and 180 day (500 hour)

Type of inspection pre-flight: visual system check; 180 day: full inflation test

Standard inspection tests

Warning/Status indicators Pushbutton light in cockpit verifies electrical system in-tact; pressure gauge on all bottles.

Component Re-usability Completely re-usable

VI. Method of Qualification/Certification

"SPIRIT" model tests.

VII. Miscellaneous Comments

NOSE FLOATS: skin covers released and remained attached at inboard side of each float.

MAIN FLOATS: MLG doors rotated to full-up position; to do this, need to sever a small link which connects door to MLG. Pyrotechnic charge is used to sever link.

NITROGEN: Simplifies service requirements, but slightly degrades performance (weight, buoyancy, inflation time).

Model: H-46 (HEFS) Rotorcraft Flotation Study : Flotation System Technical Survey

I. System Description

# Floats	2	# bottles	4 AIDs (Augmented Inflation Devices)
Cells/Float	2	location of bottles	Lower inboard side of each float.
Vol./Float	140 cu.ft. (112 in. x 57 in. diameter)	bottle size	
Float Material	Urethan coated Kevlar (see miscellaneous comments)	type of gas	CO2
Mounting Location	Fuselage - aft of passenger doors: external girts	bottle pressure	0-5500-7500 psi (see Activation)
Mode of Storage	In external PODs (see miscellaneous comments)	inflation time	
Buoyancy	24,300 lbs. (see Tests in Certification)	infl. press. of floats	2.25 psi (NOT temperature dependent)

time floats remain inflated (for different operating conditions) > 3 hours (see Tests)

Weight of System
Effect on CG

II. System Operation

Arming Method: 1) Cabin mounted manual arm/off switch; 2) water level/inverted aircraft sensor; 3) Cabin mounted manual normal/emergency switch.

Activation Method: "Float Inflate" signal either by 2) or 3) above ignites solid propellant. This burns and pressure until 1st burst disc ruptures; continued buring pressure of CO2 until ~ 5500 psi; 2nd brust disc ruptures, releasing CO2 into cells and extinguishing solid propellant; 3rd burst disk ruptures at 7500 psi as backup.

III. Operating Environment Parameters

Effect on flying quality: Minimal effect on performance while stowed.
Allowable landing speed
Allowable landing attitude
Operating temperature range: Amount of solid propellant burned adjusts automatically to provide uniform and constant T&P
Operating pressure range: prior to discharge regardless of environmental T.
Water temperature
Wave size: Water ballast scoops provide counter-rotative moment during roll caused by wave action.
Wind
Permissable damage condition

IV. Installation

Procedure

V. Service Testing and Maintenance

Frequency of inspection
Type of inspection
Standard inspection tests

Warning/Status indicators: Built-in-test to indicate "go/no-go" status of floats.
Component Re-usability

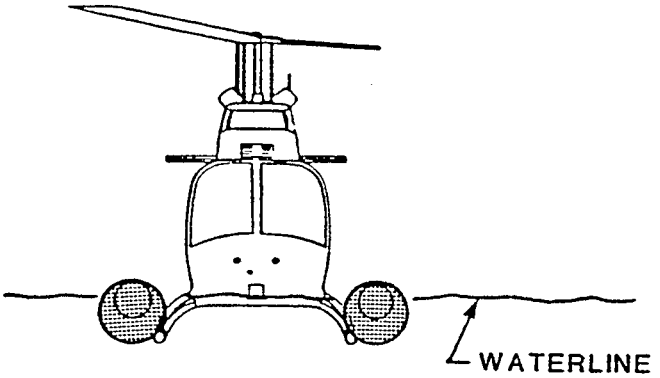
VI. Method of Qualification/Certification

DESIGN VERIFICATION TESTS: Floats and pads tested in 20 ft. and 60 ft. water integrity test tanks Boeing Vertol Company in June, 1985. Tested system deployment, float submergence. Float system mounted to fixture representing one side of H-46 fuselage.
FULL SCALE: 1) 10 Minute Tests: 13 total tests: "lowering" and "drops." by NADC in 8/85-9/85. Dynamic (drop) test described above in Allow. Ldg. speed/Attitude. 2) 3 Hour Test: fuselage was flooded, hull came to rest in stable condition ~ 12 deg. nose high with rear ran exit completely under water.

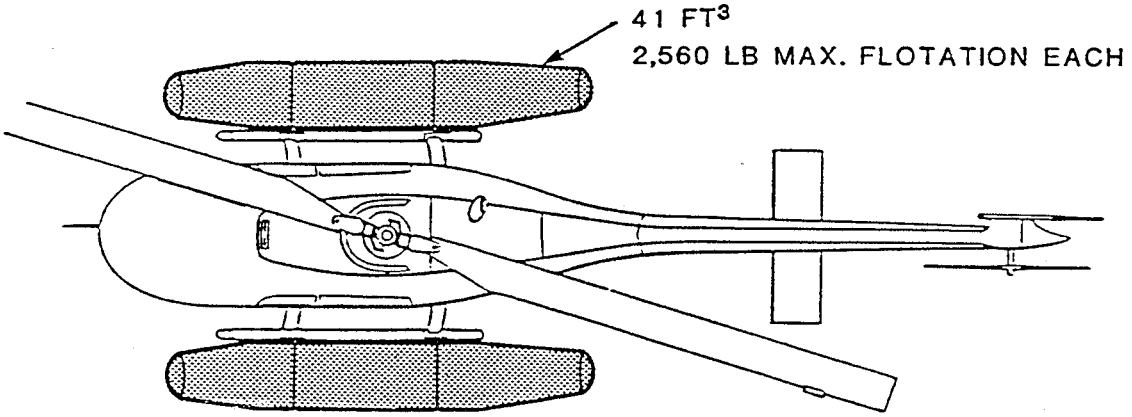
VII. Miscellaneous Comments

PODS: Rigid, lightweight, Nomex honeycomb core sandwiched between layers of fiberglass cloth; streamlined to minimize adverse aerodynamics.
KEVLAR: 2/3 the weight of equal strength nylon fabric.
SOLID PROPELLANT: This feature eliminates need for maintenance to adjust operating pressure based on ambient temp.
WATER BALLAST SCOOPS: provide counter-rotative moment during A/C roll. Hole at bottom of scoop automatically adjusts the amount of water in the scoop.

APPENDIX B—EMERGENCY FLOTATION SYSTEM LAYOUTS



A. FLOATING UPRIGHT



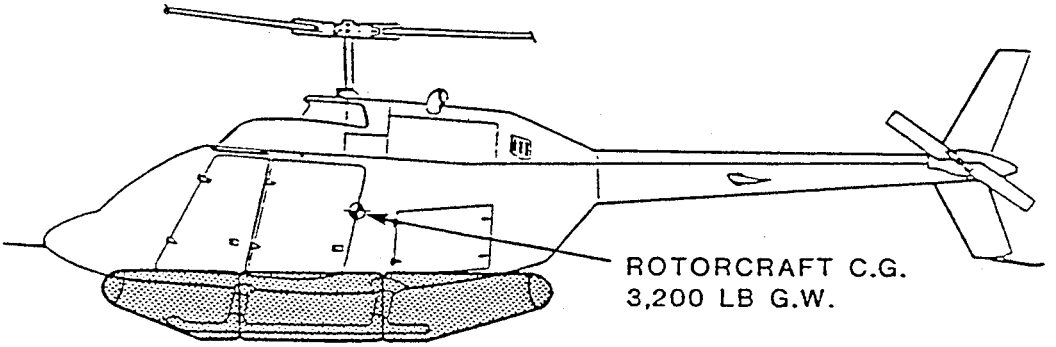


FIGURE B-1. BELL HELICOPTER TEXTRON MODEL 206 EMERGENCY FLOTATION SYSTEM

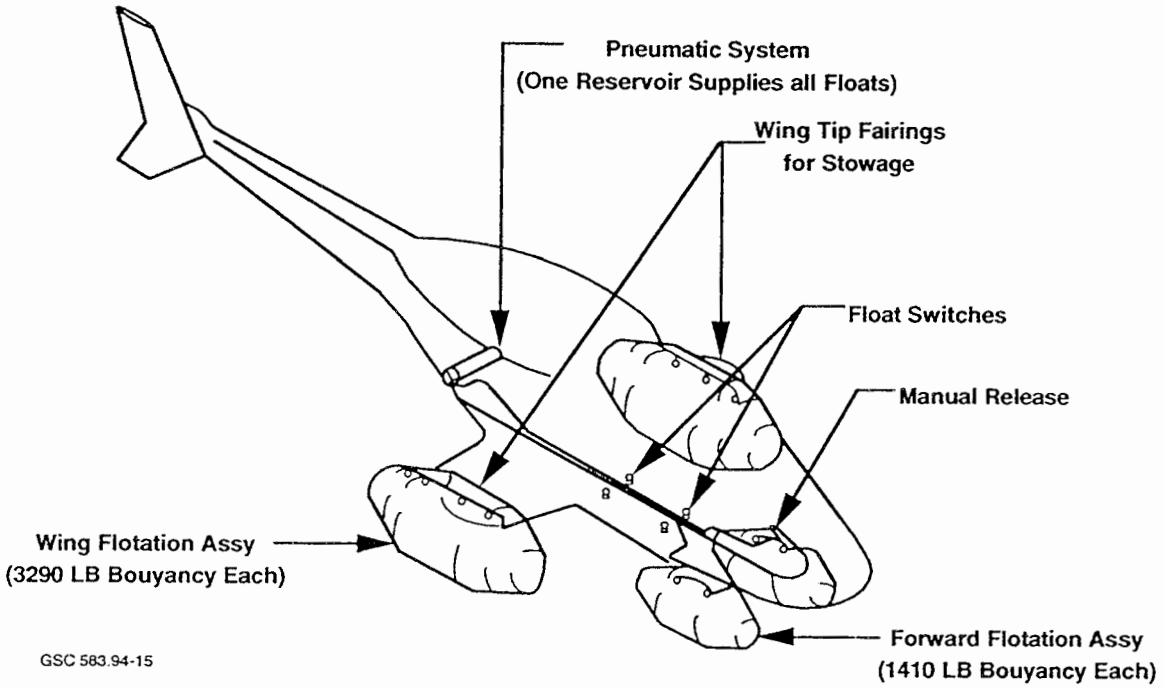


FIGURE B-2. BELL HELICOPTER TEXTRON MODEL 222 EMERGENCY FLOTATION SYSTEM

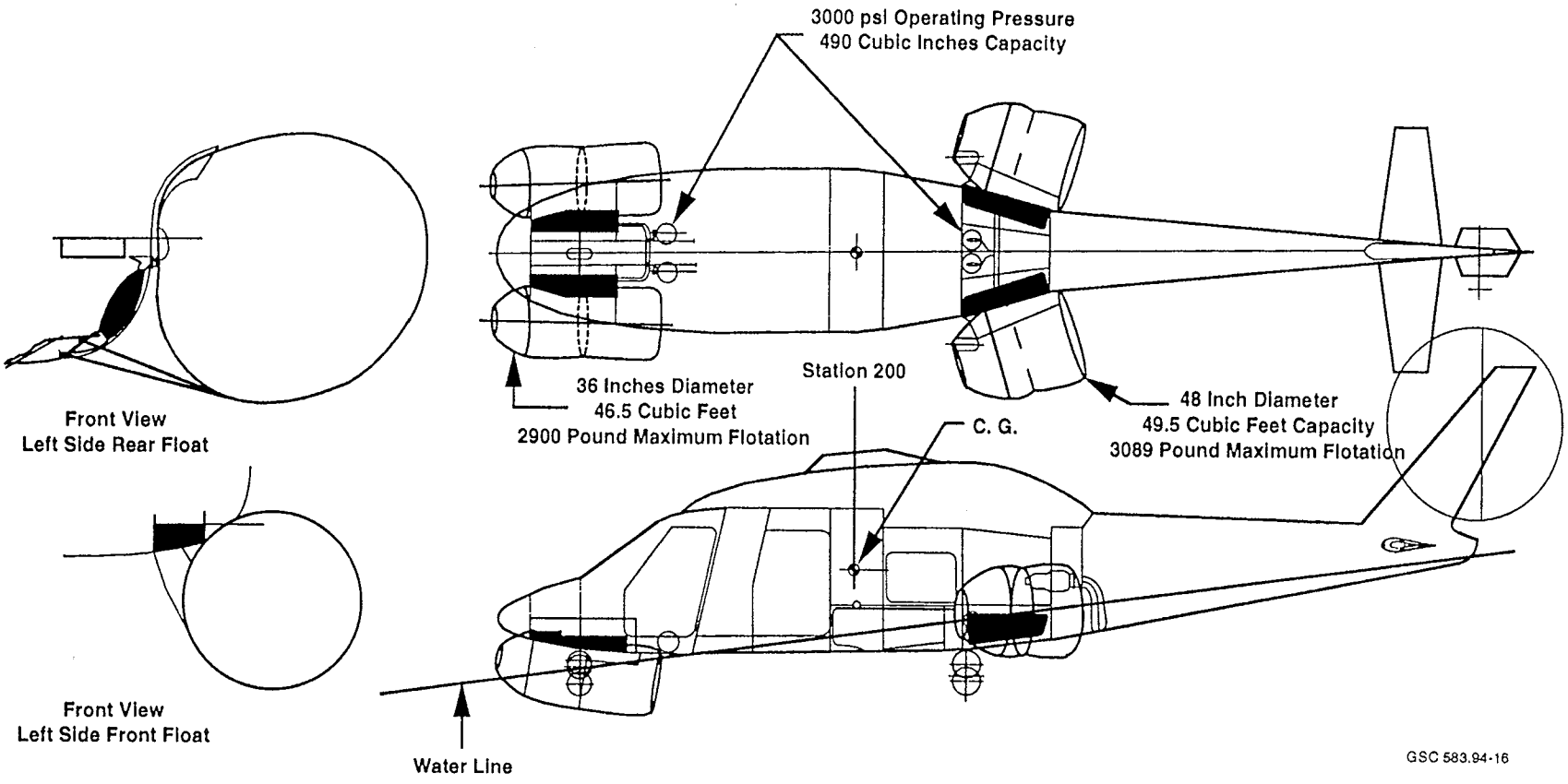


FIGURE B-3. S-76 EMERGENCY FLOAT SYSTEM

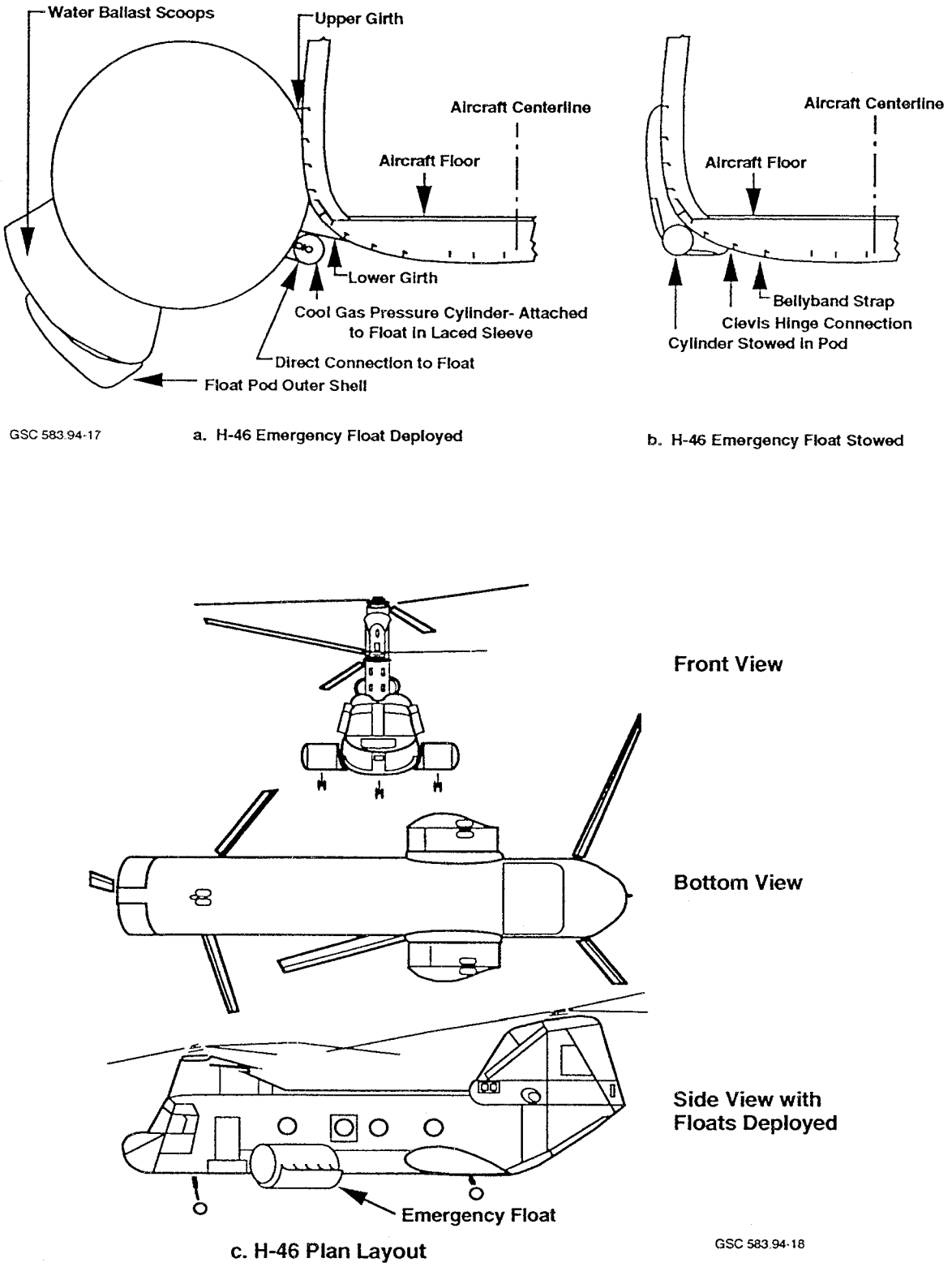


FIGURE B-4. H-46 EMERGENCY FLOTATION SYSTEM