AD-A276 473

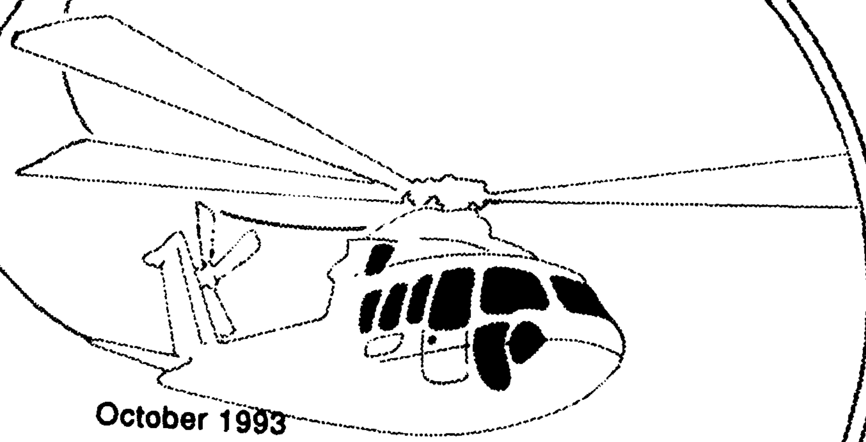
(2)

DOT/FAA/CT-92/14

FAA Technical Center
Atlantic City International Airport,
N.J. 08405

# Rotorcraft Ditchings and Water-Related Impacts that Occurred from 1982 to 1989 - Phase II

DTIC
ELECTE
MAR 07 1994
S F D



October 1993

Final Report

94-07407

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

This document has been approved for public release and sale; its distribution is unlimited.

U.S. Department of Transportation
Federal Aviation Administration

94 3 4 070

## NOTICE

This document is disseminated under the sponsorship of the U. S. Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the objective of this report.

**Technical Report Documentation Page**

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| DOT/FAA/CT-92/14 | | |

**4. Title and Subtitle**

ROTORCRAFT DITCHINGS AND WATER-RELATED IMPACTS THAT OCCURRED FROM 1982 TO 1989 -- PHASE II

**5. Report Date**

October 1993

**6. Performing Organization Code**


**7. Author(s)**

Mark Muller, Galaxy Scientific Corporation, and
Lindley W. Bark, Simula Inc.


**8. Performing Organization Report No.**


**9. Performing Organization Name and Address**

Galaxy Scientific Corporation
2500 English Creek Avenue, Building 11
Pleasantville, NJ 08232


**10. Work Unit No. (TRAIS)**

**11. Contract or Grant No.**

DTFA03-89-C-00043


**12. Sponsoring Agency Name and Address**

U.S. Department of Transportation
Federal Aviation Administration
Technical Center
Atlantic City International Airport, NJ 08405


**13. Type of Report and Period Covered**

Final Report

**14. Sponsoring Agency Code**

ACD-210

**15. Supplementary Notes**

FAA Technical Center Project Manager: Anthony Wilson


**16. Abstract**

This report documents Phase II of a two-phase effort to examine rotorcraft ditchings and water-related impacts for rotorcraft, that occurred between the years 1982 through 1989. The main tasks performed for this phase of the investigation were assessment of the effects of structure on occupant injury, determination of the specific modes of structural failure, identification of the potential means to alleviate injury, and evaluation of available analytical methods for modeling rotorcraft water impacts. The Phase II analysis examined specific aspects of the Phase I data for accidents that fulfilled the criteria for the three impact scenarios. The main impact injuries were from flailing and excessive acceleration and resulted from occupant interaction with the rotorcraft interior and insufficient energy absorption. Drowning and exposure were found to be the main post-impact hazards and other post-impact injuries were minor in severity. Structural failures of the rotorcraft are identified and discussed as they affected occupant injury. The performance and adequacy of rotorcraft flotation equipment is discussed. Means of alleviating occupant injury in rotorcraft water impacts are identified and discussed. An analytical method for modeling the water impact of a rotorcraft is evaluated.



**17. Key Words**

Rotorcraft Ditching, Injury Alleviation, Rotorcraft Water Impact, Delethalization, Water Crash Environment, Structural Failure, Analytical Methods, Aircraft Flotation


**18. Distribution Statement**

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 39 | |


Form DOT F1700.7 (8-72) Reproduction of completed page authorized

# PREFACE

This report was prepared by Galaxy Scientific Corporation and Simula, Inc. under Contract No. DTFA03-89-C-00043 with the Federal Aviation Administration (FAA) Technical Center. The Project Manager at Galaxy Scientific Corporation was Dr. Charles C.T. Chen. The authors would like to thank Mr. William Adams of the Army Safety Center and Mr. Bill Broyles of the Navy Safety Center for their valuable assistance in acquiring data for this study.

| Accesion For | | |
|---|---|---|
| NTIS CRA&I | | ☑ |
| DTIC TAB | | ☐ |
| Unannounced | | ☐ |
| Justification | | |
| By | | |
| Distribution / | | |
| Availability Codes | | |
| Dist | Avail and / or Special | |
| A-1 | | |

TABLE OF CONTENTS

## LIST OF ILLUSTRATIONS

## LIST OF TABLES

EXECUTIVE SUMMARY

This report documents Phase II of a two-phase effort to characterize the behavior of rotorcraft structure, rotorcraft flotation equipment, and personal flotation equipment as they affected occupant survivability in ditchings and water-related impacts that occurred between 1982 and 1989. The main goals of this phase were:

a. Assess what effect the structure had on occupant injury,

b. Determine the specific modes of structural failure,

c. Identify potential means to alleviate injury to occupants, and

d. Evaluate available analytical methods for their applicability to modeling rotorcraft water impacts.

The approach used in the Phase II analysis was to further examine specific aspects of the data and results of Phase I (reference 1) for accidents that fulfilled the criteria for the three impact scenarios as stated in the Phase I Final Report. This information was then analyzed to address the first three goals of Phase II. Available analytical computer models were reviewed to determine their applicability to simulate water impacts.

The main injuries suffered by occupants were caused by flailing and excessive acceleration. Drowning and exposure were the main post-impact hazards. Structural failures of the rotorcraft were not found to be significant contributors to occupant injury. The performance of rotorcraft flotation equipment, in the accident study, was not found to adequately keep the occupiable volume of the downed rotorcraft upright and afloat. Means identified for alleviating injury in rotorcraft water impacts include better occupant restraint, delethalization of the cockpit and cabin interior, energy-absorbing seats, improved performance and use of personal flotation equipment, and improved performance of rotorcraft flotation.

An analytical method for modeling water impact of a rotorcraft exists but is being evaluated and refined.

## 1. INTRODUCTION.

The main goals for Phase II of the investigation into rotorcraft ditching and water-related impacts were to determine the specific modes of structural failure, to assess what effect structure had on occupant injury, to identify potential means to alleviate injury, and to evaluate available analytical methods for their applicability to modeling rotorcraft water impacts. The following tasks were defined to achieve these goals:

a. Task I — Identify Effects of Structural Components on Injury — Using the data and results obtained in reference 1, identify injuries caused by occupant/structure interaction during water-related impacts.

b. Task II — Identify Airframe/Component Modes of Failure — Again using the data and results obtained in Phase I, identify the modes of failure for rotorcraft airframes and airframe components during water-related impacts.

c. Task III — Identify Means to Alleviate Injury — Based on the results of Tasks I and II, identify possible means to alleviate occupant injury.

d. Task IV — Review Analytical Methods — Review currently available analytical methods for their applicability to modeling rotorcraft water-related impacts.

Applicable background material from previous, similar efforts examining rotorcraft involved in impacts of water and of all terrain types is presented. The technical approach used to perform the aforementioned tasks is outlined and discussed. The results of the four tasks, including generic layouts of rotorcraft structure demonstrating injury-causing features and modes of failure, are discussed. Means to alleviate occupant injury and an assessment of analytical methods available to model water-related impacts are presented. Finally, conclusions based on the results of this phase of the investigation are presented.

## 2. BACKGROUND.

The data categorizations performed in reference 1 revealed several trends in type of injuries received in rotorcraft water impacts. The two rotorcraft weight classes with the highest numbers of fatal and serious injuries were weight class B (2500-6000 lbs design gross weight) and weight class C (6000-12500 lbs design gross weight). Another trend identified was that as rotorcraft weight increased, the number of impact injuries relative to post impact injuries decreased. The severity of impact injuries also decreased as rotorcraft weight increased. The two most significant causes of occupant injury were found to be whole body accelerative forces and flailing. Of special note was that although the velocity envelope values (defined as survivable) for rotorcraft water impacts was higher than that found in all-terrain impacts (reference 1) the overall percentage of injured occupants was lower.

The results of Phase I of the rotorcraft water impact program suggested that further investigation into the occurrence of occupant injury during water impacts was necessary because, although general hazards were identified, specific analysis could provide more useful results. By categorizing injury data according to type, cause, frequency and severity, general hazards to occupant survivability were identified. It further concluded that examination of injury data relative to the layout of the rotorcraft would help to better define the crash environment and determine ways of alleviating hazards to occupants.

In addition to examining the immediate surroundings of the occupant during a water impact sequence, the behavior of the overall rotorcraft structure during the impact must also be considered. The behavior of the rotorcraft structure during an impact sequence is a significant factor in occupant survivability. The structure should:

a. Maintain a protective structural envelope around the occupants, and

b. Help to attenuate the impact forces to maintain survivable acceleration conditions for the occupants.

Examination of structural damage data focused on the damage particular sections of the rotorcraft received and determined whether that damage contributed to occupant injury. The scenarios established in Phase I for water impact describe the typical ways that rotorcraft impacted the water surface. These scenarios are defined by the flight path angle, the rotorcraft attitude, and the relative magnitude of the rotorcraft's velocity components. So these scenarios can be used for assessing a rotorcraft's crash behavior.

The impact loads in a water impact are significantly different from those experienced in a ground impact. In a water impact the landing gear of the rotorcraft does not absorb significant impact energy and the impact load is distributed over a wider contact area (reference 2). Therefore, there is a need to specifically examine the effects of a water impact on the structure of a rotorcraft and how the resulting damage affects occupant injury and survivability.

A method of modeling the effects of a defined crash environment on a rotorcraft and its occupants is necessary to assess any proposed safety improvements. The need for such a method becomes apparent when considering how to evaluate the behavior of an airframe and its occupants when subjected to a variety of impact conditions. Such evaluation will help assess the crashworthiness of a particular airframe. Full-scale testing, if the only method available, is impractical due to its high costs. Computerized analytical techniques provide a cost-effective means of assessing a rotorcraft's crashworthiness. Validated computer programs currently exist that can model rotorcraft impacts on rigid ground. Therefore, an investigation into the applicability of such computer models to water impacts would facilitate further crashworthiness improvements.

## 3. TECHNICAL APPROACH.

The main goals for Phase II of the investigation into rotorcraft ditching and water-related impacts were to:

a. Determine the specific modes of structural failure,

b. Assess what effect structure had on occupant injury,

c. Identify potential means to alleviate injury, and

d. Evaluate available analytical methods for their applicability to modeling rotorcraft water impacts.

Phase I of this program focused on categorizing the impact and post impact conditions involved in water-related impacts of rotorcraft such as the impact attitudes, velocities, and wave heights. Also examined were occupant injury types, causes, severity, and relation to impact. The damage incurred by the rotorcraft involved in these accidents was also documented but was not discussed in the Phase I interim report. Three scenarios were established to describe the typical impact sequences encountered in the accident sample. These three water impact scenarios were defined as follows:

Impact Scenario 1 — Predominately high vertical impact velocity:

a. Flight path angle greater than or equal to 45 degrees,

b. Vertical impact velocity component greater than the longitudinal velocity component,

c. Roll angle between ± 20 degrees, and

d. Pitch angle between ± 20 degrees.

A total of 27 accident cases, 36 percent of the total Phase I sample, were identified with scenario 1.

Impact Scenario 2 — Predominately high longitudinal impact velocity (low flight path angle):

a. Flight path angle between 0 and 20 degrees.
b. Longitudinal impact velocity component greater than the vertical component,
c. Roll angle between ± 20 degrees,
d. Pitch angle between ± 20 degrees, and
e. Yaw angle between ± 20 degrees.

A total of 13 cases, 17 percent of the total Phase I sample, were found in scenario 2.

Impact Scenario 3 — Predominately high longitudinal impact velocity (high flight path angle):

a. Resultant angle greater than or equal to 45 degrees,

b. Longitudinal impact velocity component greater than the vertical velocity component, and

c. Pitch angle between -20 degrees and -90 degrees.

A total of 6 cases, 8 percent of the Phase I sample, fulfilled the criteria for scenario 3.

This study examines specific aspects of the data generated in reference 1 for the three impact scenarios. A significant part of the analysis of occupant/structure interaction and airframe modes of failure was the development of generic airframe layouts typical of rotorcraft encountered in the sample. These generic layouts were then used to identify injury-causing features and types of structural failure. The creation of these generic layouts was guided by the following considerations observed in the results of reference 1:

a. Frequency of impact injury by weight class, and
b. Frequency of occurrence of rotorcraft model by weight class.

It was determined that weight classes B and C contained the most impact-related injuries. Therefore, the analysis focused on these two weight classes. The three most frequently occurring models in each weight class were determined. Structural details were then taken from these models to create generic layouts of the rotorcraft interior and overall airframe. It was intended that these two generic layouts be typical of civil rotorcraft of weight class B and C. Appendix A details these generic rotorcraft layouts.

## 4. EFFECTS OF STRUCTURAL COMPONENTS ON INJURY.

### 4.1 APPROACH - IMPACT AND POST-IMPACT INJURIES.

In the selected accidents chosen from Phase I for further analysis, the interactions between the occupants and the rotorcraft structure during the impact and post-impact sequences were examined to assess whether and how these interactions resulted in injury. The following occupant information was collected from each accident report where available for weight class B and weight class C rotorcraft:

a. Seating location of occupant,
b. Body location of injury,
c. Type, cause, and severity of injury, and
d. Narrative description of accident.

The specific causes of injury to the occupants, as well as the nature and severity of these injuries, was investigated to identify means to alleviate those injuries determined to be a significant hazard to occupant safety. The computerized database and the reconstructed accidents from Phase I were used with the generic helicopter layouts to assess occupant injuries.

The impact injuries recorded in Phase I were classified by impact scenario and rotorcraft weight class. The categorization by impact scenario was performed to determine if the impact parameters of the rotorcraft affected the type, frequency, or severity of injuries received. Also, the categorization by rotorcraft weight class provided a means to assess the relationship between rotorcraft weight and the occupant injuries.

Post-impact injuries recorded in Phase I were also examined in greater detail. These injuries were also classified by impact scenario and rotorcraft weight class. The interaction of the occupants with the downed rotorcraft were examined to determine whether this interaction produced injury or impeded egress. The categorization by impact scenario and weight class was performed with special attention being given to determining the relationship between impact injuries and other injuries, especially drowning.

## 4.2 RESULTS - IMPACT INJURIES.

Table 1 lists the overall occupant injury severity distribution for weight class B and C. The percentage of serious and fatal injury is significantly higher in weight classes B rotorcraft than it is in weight class C rotorcraft. It should be noted that all of the fatalities in weight class C rotorcraft were caused by drowning and were not directly impact-related. Table 2 categorizes the accidents by weight class and impact scenario type and also gives the number of accidents in each category. There were no accidents of weight class C rotorcraft that satisfied the definition for impact scenario 3. Categorization by weight class and impact scenario type was used frequently in the analysis, therefore, the number of accidents investigated for each condition is noted.

TABLE 1. OCCUPANT INJURY SEVERITY DISTRIBUTION BY ROTORCRAFT WEIGHT CLASS

| Injury Severity | Weight Class B | | Weight Class C | |
|---|---|---|---|---|
| | Number of Occupants | Percent | Number of Occupants | Percent |
| Fatal | 32 | 25 | 6 | 10 |
| Serious | 23 | 18 | 6 | 10 |
| Minor | 26 | 20 | 8 | 13 |
| None | 48 | 37 | 40 | 67 |
| Total | 129 | 100 | 60 | 100 |

Total number of Rotorcraft Weight Class B and Class C accidents = 58

TABLE 2. ACCIDENT SAMPLE DISTRIBUTION BY IMPACT SCENARIO AND ROTORCRAFT WEIGHT CLASS

| Impact Scenario | Number of Accidents | |
|---|---|---|
| | Weight Class B | Weight Class C |
| 1. Predominantly High Vertical Impact Velocity | 11 | 8 |
| 2. Predominantly High Longitudinal Impact Velocity (low FP angle) | 8 | 4 |
| 3. Predominantly High Longitudinal Impact Velocity (high FP angle) | 3 | 0 |
| Total | 22 | 12 |

Total number of Rotorcraft Weight Class B and Class C accidents in impact scenarios = 34

The two significant groups of impact injury types in the sample were those attributed to flailing and those attributed to whole body acceleration. The distribution of impact injury types by impact scenario type and rotorcraft weight class is shown in table 3. Injury types such as concussions, fractures, and sprains are indicative of occupant flailing. Some of these sprains and fractures are injuries of the spine caused by accelerative forces in excess of human tolerance.

TABLE 3. IMPACT INJURY TYPE DISTRIBUTION BY IMPACT SCENARIO AND ROTORCRAFT WEIGHT CLASS

| Impact Scenario | Weight Class B | | Weight Class C | |
|---|---|---|---|---|
| | Injury Cause | No. | Injury Cause | No. |
| 1. Predominantly High Vertical Impact Velocity | concussion | 1 | abrasion | 1 |
| | fracture | 3 | concussion | 1 |
| | laceration | 3 | contusion | 6 |
| | strain | 1 | dislocation | 1 |
| | unknown type | 4 | fracture | 5 |
| | | | laceration | 3 |
| | | | sprain | 1 |
| | | | unknown type | 2 |
| | Total | 12 | Total | 20 |
| 2. Predominantly High Longitudinal Impact Velocity (low FP Angle) | abrasion | 5 | fracture | 4 |
| | contusion | 5 | strain | 1 |
| | laceration | 2 | unknown type | 1 |
| | strain | 1 | | |
| | unknown type | 5 | | |
| | Total | 18 | Total | 6 |

TABLE 3. IMPACT INJURY TYPE DISTRIBUTION BY IMPACT SCENARIO AND ROTORCRAFT WEIGHT CLASS (CONTINUED)

| Impact Scenario | Weight Class B | | Weight Class C | |
|---|---|---|---|---|
| | Injury Cause | No. | Injury Cause | No. |
| 3. Predominantly High Longitudinal Impact Velocity (high FP Angle) | abrasion | 1 | | |
| | crush | 1 | | |
| | dislocation | 2 | | |
| | fracture | 9 | | |
| | laceration | 3 | | |
| | severance | 1 | | |
| | unknown type | 3 | | |
| | Total | 20 | Total | 0 |

Similar injury types were experienced by occupants in all three impact scenarios, although the distributions differed. The distribution of causes for these impact injuries, shown in table 4, supports this finding. Although the number of injury causes listed as unknown is rather large, knowledge of the types of injuries helps to identify the hazard to the occupant. The causes that are listed in table 4, such as the instrument panel and the side console, are typical causes of flailing injuries. Acceleration is listed specifically as a cause in all three impact scenarios.

TABLE 4. IMPACT INJURY CAUSE DISTRIBUTION BY IMPACT SCENARIO AND ROTORCRAFT WEIGHT CLASS

| Impact Scenario | Weight Class B | | Weight Class C | |
|---|---|---|---|---|
| | Injury Cause | No. | Injury Cause | No. |
| 1. Predominantly High Vertical Impact Velocity | acceleration | 5 | acceleration | 4 |
| | unknown cause | 7 | control stick/cyclic | 1 |
| | | | instrument panel | 3 |
| | | | seatbelt - tiedown | 3 |
| | | | side console | 1 |
| | | | windshield frame | 5 |
| | | | other | 1 |
| | | | unknown cause | 2 |
| | Total | 12 | Total | 20 |
| 2. Predominantly High Longitudinal Impact Velocity (low FP Angle) | seat | 3 | acceleration | 4 |
| | seatbelt - tiedown | 1 | unknown cause | 2 |
| | shoulder harness | 1 | | |
| | other | 3 | | |
| | unknown cause | 10 | | |
| | Total | 18 | Total | 6 |

TABLE 4. IMPACT INJURY CAUSE DISTRIBUTION BY IMPACT SCENARIO AND ROTORCRAFT WEIGHT CLASS (CONTINUED)

| Impact Scenario | Weight Class B | | Weight Class C | |
|---|---|---|---|---|
| | Injury Cause | No. | Injury Cause | No. |
| 3. Predominantly High Longitudinal Impact Velocity (high FP Angle) | acceleration<br>instrument panel<br>unknown cause | 4<br>1<br>15 | | |
| | Total | 20 | Total | 0 |

Table 5 presents the definitions of the Accident Injury Scale severity codes used to classify the injuries. The distribution of the severity of the impact injuries, by impact scenario and by rotorcraft weight class, is presented in table 6. It is of note that there was only one impact injury received by occupants in weight class C rotorcraft higher than AIS severity 3. All of

TABLE 5. DEFINITION OF AIS SEVERITY CODES

| AIS CODE | Definition |
|---|---|
| 0 | Not injured |
| 1 | Minor injury |
| 2 | Moderate injury |
| 3 | Serious injury(not life-threatening) |
| 4 | Severe injury (life-threatening, survival probable) |
| 5 | Critical injury (survival uncertain) |
| 6 | Maximum (untreatable - fatal) |
| 7 | Injured (unknown severity) |
| 88 | Unknown if injured |

TABLE 6. AIS IMPACT INJURY SEVERITY DISTRIBUTION BY IMPACT SCENARIO AND ROTORCRAFT WEIGHT CLASS

| Impact Scenario | Weight Class B | | Weight Class C | |
|---|---|---|---|---|
| | AIS Injury Severity | No. | AIS Injury Severity | No. |
| 1. Predominantly High Vertical Impact Velocity | minor<br>moderate<br>serious | 5<br>1<br>6 | minor<br>moderate<br>serious<br>severe | 9<br>4<br>6<br>1 |
| | Total | 12 | Total | 20 |
| 2. Predominantly High Longitudinal Impact Velocity (low FP Angle) | minor<br>moderate<br>serious<br>unknown severity | 6<br>1<br>10<br>1 | minor<br>serious | 4<br>2 |
| | Total | 18 | Total | 6 |

TABLE 6. AIS IMPACT INJURY SEVERITY DISTRIBUTION BY IMPACT SCENARIO AND ROTORCRAFT WEIGHT CLASS (CONTINUED)

| Impact Scenario | Weight Class B | | Weight Class C | |
|---|---|---|---|---|
| | AIS Injury Severity | No. | AIS Injury Severity | No. |
| 3. Predominantly High Longitudinal Impact Velocity (high FP Angle) | minor<br>serious<br>severe<br>fatal | 4<br>10<br>1<br>5 | | |
| | Total | 20 | Total | 0 |

the fatal injuries were sustained by occupants involved in scenario 3 impacts, which demonstrates the severity of this crash scenario.

Categorization of the impact injuries by body location, type, and severity illustrates in detail the hazards experienced by occupants in the examined water impacts accidents. A composite depiction of the impact injuries by body location is presented in figure 1 for rotorcraft weight class B, and figure 2 for rotorcraft weight class C, according to AIS severity. The presentation of these impact injuries is further categorized by crew and passenger seating locations. Each arrow represents a separate injury recorded for occupants in the seating location identified. Injuries whose type or body location were unknown are not depicted.

These figures show that serious impact injuries of the back, torso, and head, which can be debilitating and costly, were observed in occupants of both weight classes. The injuries depicted on the arms and legs further demonstrates flailing to be a significant injury mechanism experienced in water impacts. It should be noted that there is a bias towards crew injuries in weight class B because of the higher number of occupants in the sample that were seated in crew positions.

## WEIGHT CLASS B OCCUPANT INJURIES

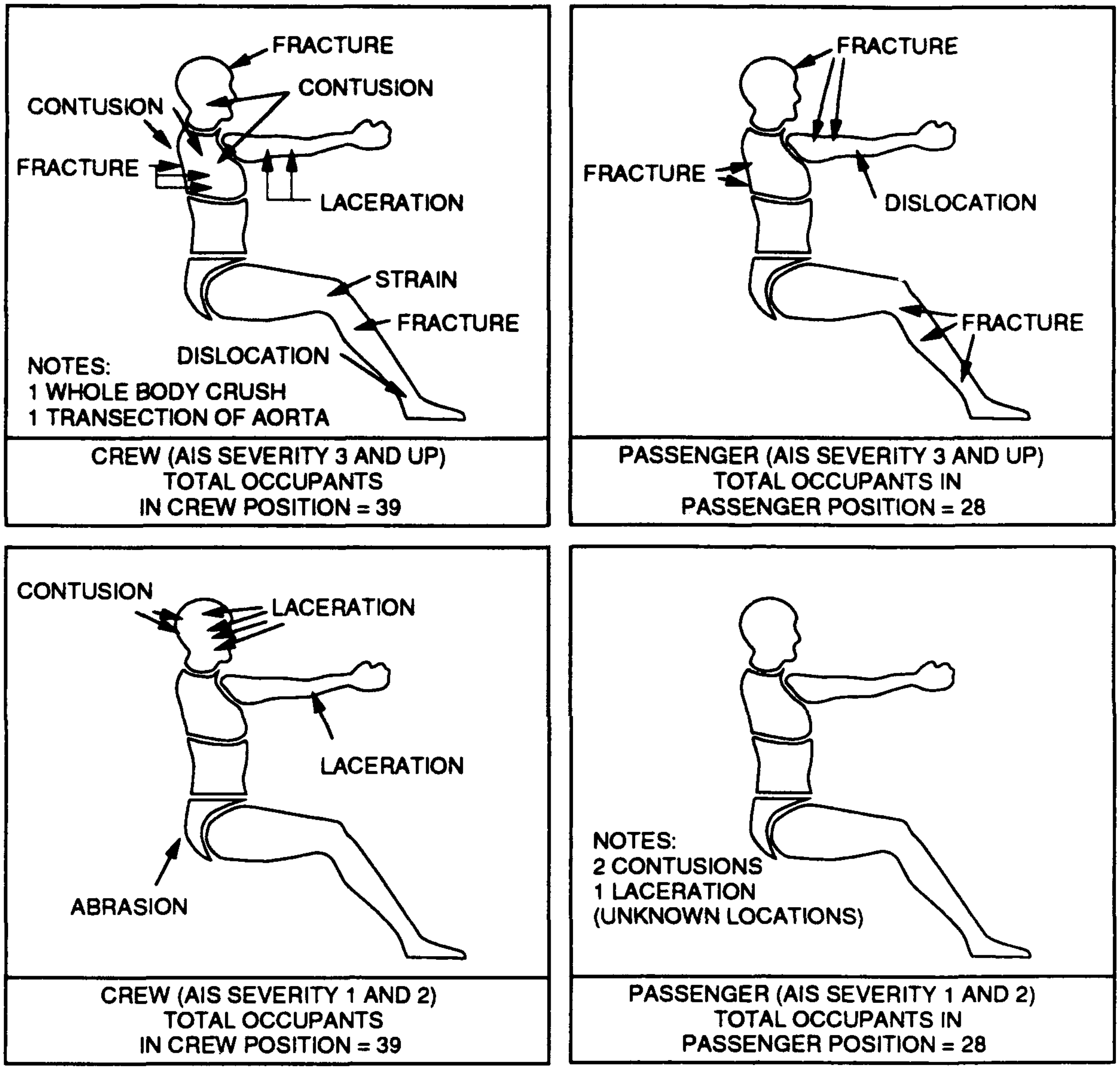



FIGURE 1. IMPACT INJURIES CLASSIFIED BY TYPE, SEVERITY, AND BODY LOCATION FOR ROTORCRAFT WEIGHT CLASS B OCCUPANTS

## WEIGHT CLASS C OCCUPANT INJURIES

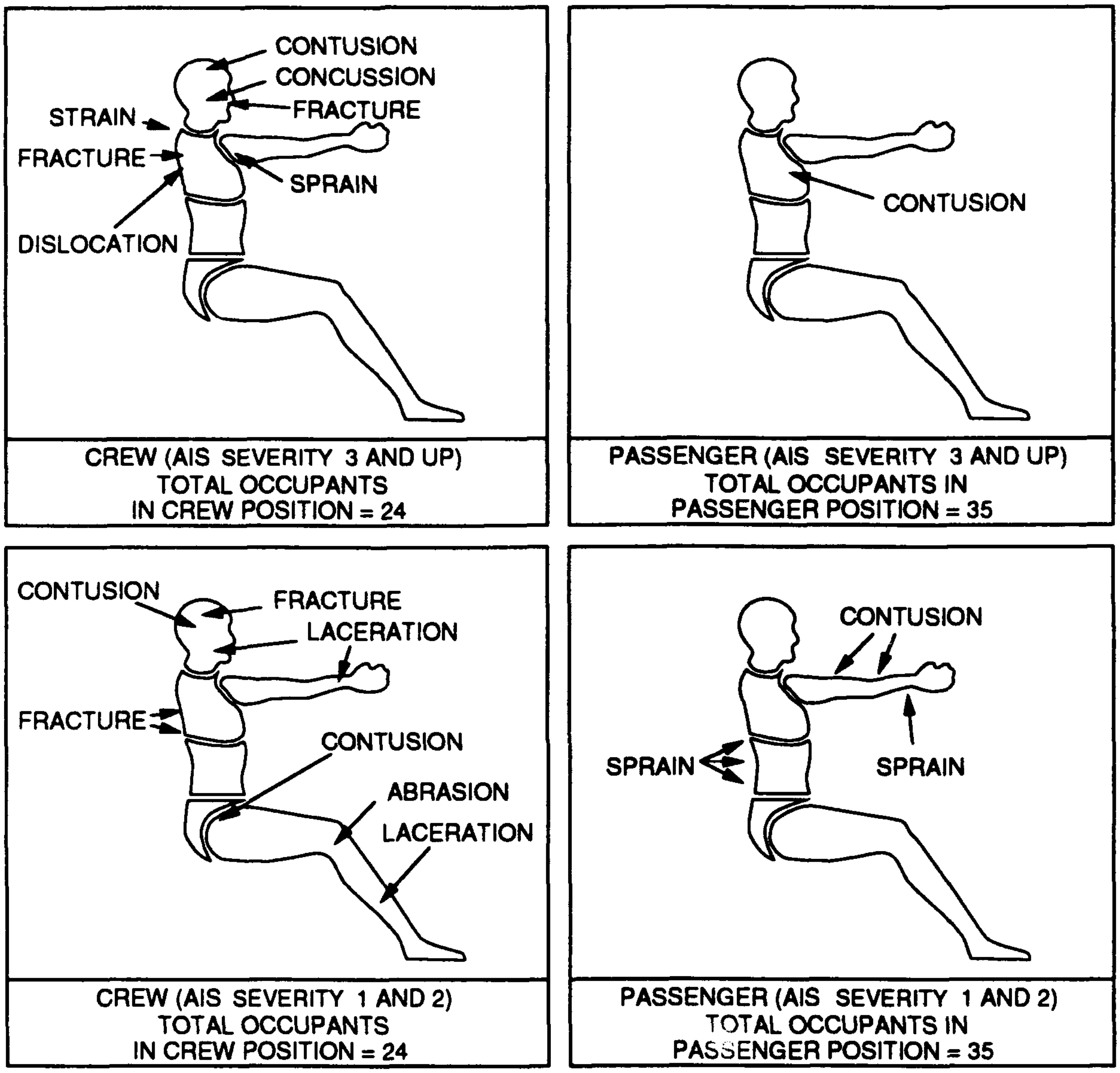
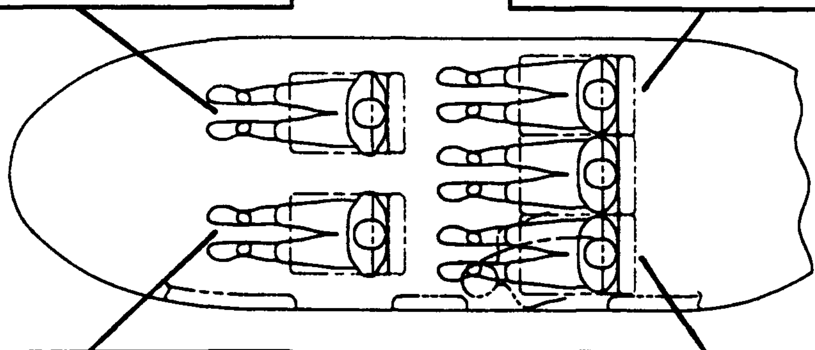



FIGURE 2. IMPACT INJURIES CLASSIFIED BY TYPE, SEVERITY, AND BODY LOCATION FOR ROTORCRAFT WEIGHT CLASS C OCCUPANTS

Figure 3 and figure 4 show impact injuries relative to a top view of occupant seating position to further demonstrate that similar injury types were experienced by occupants throughout the rotorcraft. Even considering the effect of the bias towards crew injuries as mentioned, crew occupants still suffered more impact injuries than passengers. The proximity of the crew to equipment such as the instrument panel and flight controls, which can cause injury during flailing, is believed to account for the increased frequency of crew injury. No significant differences in injury types by seating location were observed when categorizations by scenario type were performed.

| Front Right | |
|---|---|
| Injury Type | Number |
| Contusion | 2 |
| Dislocation | 1 |
| Fracture | 3 |
| Laceration | 1 |
| Strain | 1 |
| Total | 8 |

| Rear Right | |
|---|---|
| Injury Type | Number |
| Dislocation | 1 |
| Fracture | 4 |
| Total | 5 |



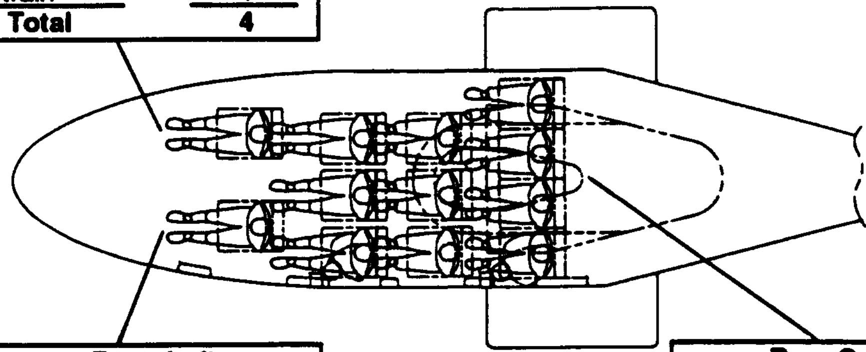
| Front Left | |
|---|---|
| Injury Type | Number |
| Contusion | 2 |
| Fracture | 1 |
| Laceration | 1 |
| Total | 4 |

| Rear Left | |
|---|---|
| Injury Type | Number |
| Fracture | 4 |
| Total | 4 |

Total Number of Weight Class B Occupants = 67

FIGURE 3. OCCUPANT IMPACT INJURY TYPES (AIS SEVERITY 3 AND UP) BY SEATING LOCATION, ROTORCRAFT WEIGHT CLASS B

| Front Right | |
|---|---|
| Injury Type | Number |
| Concussion | 1 |
| Contusion | 1 |
| Dislocation | 1 |
| Strain | 1 |
| Total | 4 |



| Front Left | |
|---|---|
| Injury Type | Number |
| Fracture | 2 |
| Sprain | 1 |
| Total | 3 |

| Rear Center | |
|---|---|
| Injury Type | Number |
| Laceration | 1 |
| Total | 1 |

Total Number of Weight Class C Occupants = 59

FIGURE 4. OCCUPANT IMPACT INJURY TYPES (AIS SEVERITY 3 AND UP) BY SEATING LOCATION, ROTORCRAFT WEIGHT CLASS C

It was found that accidents defined by scenario type for weight classes B and C exhibited occupant survivability hazards representative of the entire sample for these weight classes. This analysis focused on those accidents in weight classes B and C whose impact parameters fulfilled a defined impact scenario. The impact injuries received in accidents that did not correspond to a defined impact scenario were also examined to ensure that significant hazards were not being overlooked. In those accidents not corresponding to a defined scenario, the majority of fatalities occurred in accidents judged to be nonsurvivable.

## 4.3 RESULTS - POST-IMPACT INJURIES.

Post-impact fatalities were found to be predominantly drowning related, although there were some other types of injuries noted. Tables 7, 8 and 9 present the post impact injury distributions by type, cause and severity for accidents with defined impact scenarios and involving weight classes B and C rotorcraft. Other post impact injuries were varied in type. Two occupants received chemical burns. Several minor lacerations were experienced by occupants as they exited the rotorcraft. A ruptured eardrum was reported by an occupant that egressed from a submerged rotorcraft.

The relationships between impact and post-impact injuries were also examined to determine if the hazards posed by water impact environment reduced post-impact survivability compared to land impacts. It would be expected that serious impact injuries would impede occupants from successfully coping with the water environment. Of the 17 that received post-impact injuries, for only three occupants can it be said that impact injuries contributed to post-impact injury. One of these three occupants received multiple lacerations and contusions and also suffered a severe concussion at impact. He was then reported to have drowned. Two other occupants also drowned, one after having received multiple impact injuries and the other after receiving a serious fracture in the chest area. Seven people drowned with no known impact injuries.

TABLE 7. POST-IMPACT INJURY TYPE DISTRIBUTION BY IMPACT SCENARIO AND ROTORCRAFT WEIGHT CLASS

| Impact Scenario | Weight Class B | | Weight Class C | |
|---|---|---|---|---|
| | Injury Type | No. | Injury Type | No. |
| 1. Predominantly High Vertical Impact Velocity | suffocation/drowning | 1 | rupture<br>suffocation/drowning | 1<br>3 |
| | Total | 1 | Total | 4 |
| 2. Predominantly High Longitudinal Impact Velocity (low FP Angle) | laceration<br>suffocation/drowning | 1<br>1 | chemical burn<br>laceration<br>strain<br>suffocation/drowning<br>other | 2<br>3<br>1<br>3<br>2 |
| | Total | 2 | Total | 11 |
| 3. Predominantly High Longitudinal Impact Velocity (high FP Angle) | suffocation/drowning | 2 | | |
| | Total | 2 | Total | 0 |

TABLE 8. POST-IMPACT INJURY CAUSE BY IMPACT SCENARIO AND ROTORCRAFT WEIGHT CLASS

| Impact Scenario | Weight Class B | | Weight Class C | |
|---|---|---|---|---|
| | Injury Cause | No. | Injury Cause | No. |
| 1. Predominantly High Vertical Impact Velocity | water inhalation | 1 | water inhalation<br>other | 3<br>1 |
| | Total | 1 | Total | 4 |
| 2. Predominantly High Longitudinal Impact Velocity (low FP Angle) | door/hatches<br>water inhalation | 1<br>1 | door/hatches<br>escape rope/tape<br>exposure<br>water inhalation<br>other<br>unknown | 1<br>1<br>2<br>3<br>2<br>2 |
| | Total | 2 | Total | 11 |
| 3. Predominantly High Longitudinal Impact Velocity (high FP Angle) | water inhalation | 2 | | |
| | Total | 2 | Total | 0 |

TABLE 9. AIS POST-IMPACT INJURY SEVERITY BY IMPACT SCENARIO AND ROTORCRAFT WEIGHT CLASS

| Impact Scenario | Weight Class B | | Weight Class C | |
|---|---|---|---|---|
| | AIS Injury Severity | No. | AIS Injury Severity | No. |
| 1. Predominantly High Vertical Impact Velocity | fatal | 1 | minor<br>fatal | 1<br>3 |
| | Total | 1 | Total | 4 |
| 2. Predominantly High Longitudinal Impact Velocity (low FP Angle) | serious<br>fatal | 1<br>1 | minor<br>moderate<br>severe<br>fatal | 3<br>3<br>2<br>3 |
| | Total | 2 | Total | 11 |
| 3. Predominantly High Longitudinal Impact Velocity (high FP Angle) | fatal | 2 | | |
| | Total | 2 | Total | 0 |

## 5. AIRFRAME AND AIRFRAME COMPONENT MODES OF FAILURE.

### 5.1 APPROACH.

The data obtained in reference 1 on rotorcraft structural damage was examined to identify damage trends suffered in water impacts. The following rotorcraft damage information was collected from each accident report, where available, for weight classes B and C:

a. specific details describing impact damage including factual, witness narrative, and photographic evidence;

b. impact scenario (impact conditions) in which impact occurred.

This information was used with the generic airframe structure layout to determine typical damage for the various components of the rotorcraft structure. This damage was categorized by rotorcraft weight class and impact scenario type to assess the relationships between rotorcraft weight, impact parameters, and the damage to the rotorcraft. It was important to determine if the structural damage experienced by rotorcraft in water-related impacts affected the occupiable volume, thereby jeopardizing occupant survivability. The impact damage to the rotorcraft floats was also considered.

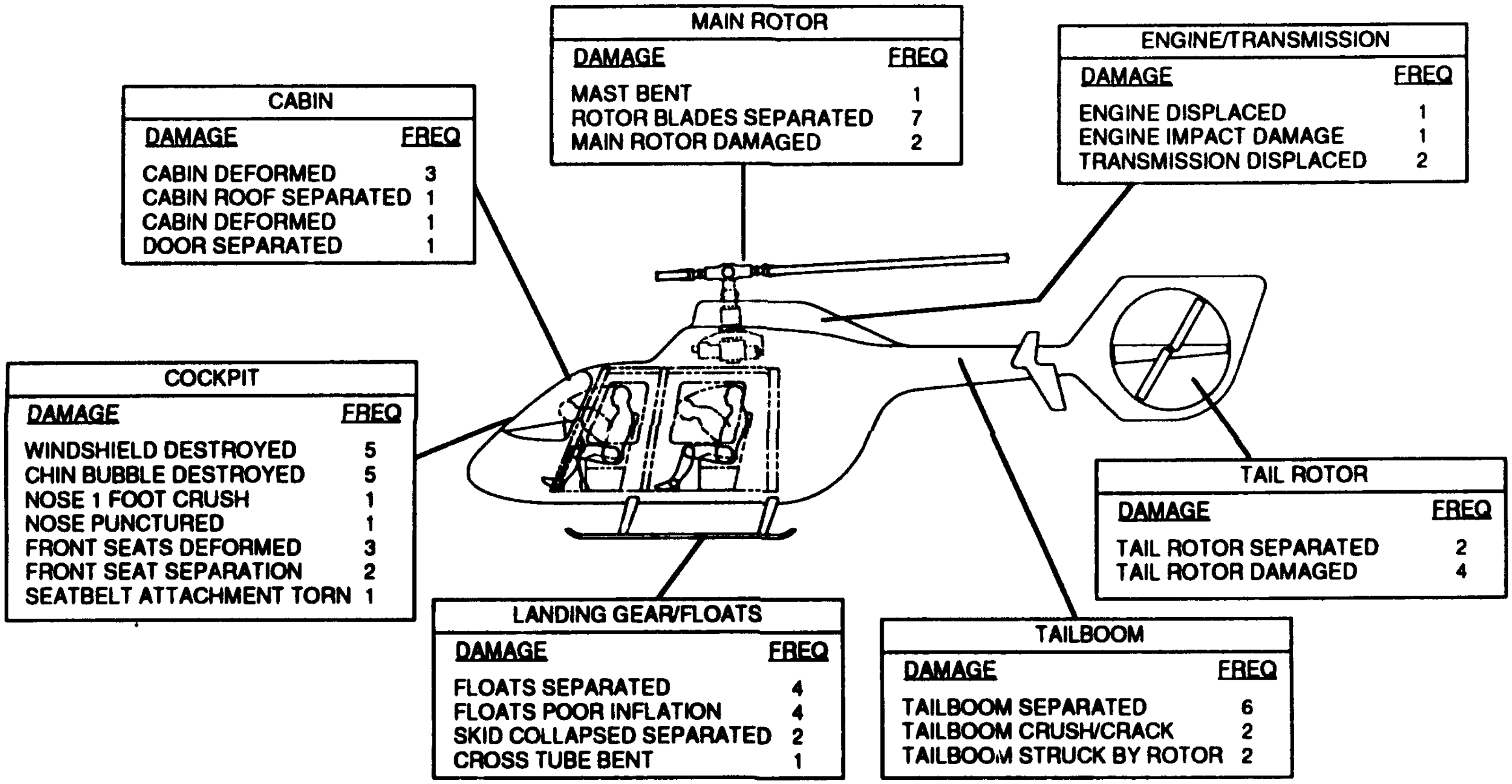
The generic layouts were used to illustrate the relationship between the structural damage and the occupiable cabin volume. The structural damage was categorized according to the section or component of the airframe affected and the type of damage that occurred. Twenty-four accident cases had descriptions containing various details of the structural damage incurred by the rotorcraft.

### 5.2 RESULTS - ROTORCRAFT WEIGHT CLASS B.

The results of the rotorcraft damage categorization were summarized by rotorcraft weight class. Figure 5 presents a composite summary of damage that was experienced by rotorcraft of weight class B. A total of 15 of the 22 weight class B rotorcraft impacts that were defined by scenarios had detailed impact damage descriptions. The damage was categorized by the airframe component affected, the type of damage suffered, and the frequency of damage reported.

#### 5.2.1 Discussion of Rotorcraft Impact Damage.

Cockpit and Cabin — The cockpit and cabin section of the rotorcraft together comprise the occupied volume which must be maintained around the occupants. The most frequently occurring type of damage noted to the cockpit was breakage of the windshield and chin bubbles at impact, which probably contributed to lacerations received by occupants in crew seating locations. Some crush and penetration of the nose structure was also noted. Deformation of seats was observed and indicates high impact accelerative forces which is consistent with the impact injuries received. Separation of seats from the rotorcraft can be




Total Number of Weight Class B Helicopters = 22

FIGURE 5. SUMMARY OF IMPACT DAMAGE FOR WEIGHT CLASS B ROTORCRAFT

a significant cause of occupant injury but was noted in only two cases. The separation of the cabin roof occurred in a severe but partially survivable accident which had a nose-down impact. This accident does not represent a typical water accident event; however, it is included for completeness.

Engine/Transmission — The engine and transmission represent large masses above the occupants (figure 5). This mounting configuration provides the potential for these masses to break loose and enter the occupied cabin volume. Although there were two occurrences of the transmission being displaced, these components were successfully retained in the 22 accidents examined.

Landing Gear/Floats — Damage to the landing gear was observed in only two cases and suggests that the skid landing gear does not contribute to energy absorption in water impacts. Float separation and poor inflation was noted in several cases and demonstrates the deficiencies in rotorcraft flotation equipment as reported in reference 1.

Main Rotor — Separation or other damage to the main rotor blades were frequently recorded. Several blades were damaged due to contact with either the tail boom or the water as the downed rotorcraft rolled. There were no recorded occurrences of main rotor damage contributing to occupant injury.

Tail Boom/Tail Rotor — Damage to the tail boom and tail rotor, especially separation from the rotorcraft, was observed frequently. Impact damage to these components, however, generally does not affect occupant survivability.

## 5.3 RESULTS - ROTORCRAFT WEIGHT CLASS C.

The results of the rotorcraft damage categorization for weight class C is presented in figure 6. A total of 9 of the 12 class C rotorcraft impacts defined by scenarios contained detailed impact damage descriptions. The damage was organized by the airframe component affected, the type of damage suffered, and the frequency of damage reported.

### 5.3.1 Discussion of Damage.

Cockpit and Cabin — Damage to the cockpit of weight class C rotorcraft was similar in type to that received by weight class B rotorcraft, though the frequency of windshield and chin bubble breakage was significantly lower in weight class C. Floor crush and cabin roof deformation are notable damage types because they may reduce the occupiable volume, however this damage was not reported to have caused injuries. Fuel tank rupture is significant because of the potential for post-crash fire, but none were reported. Fuel spilled onto the water was noted to have caused two cases of chemical burns. Deformation of door frames or jamming of a door can impede occupant egress but this damage was not frequent.

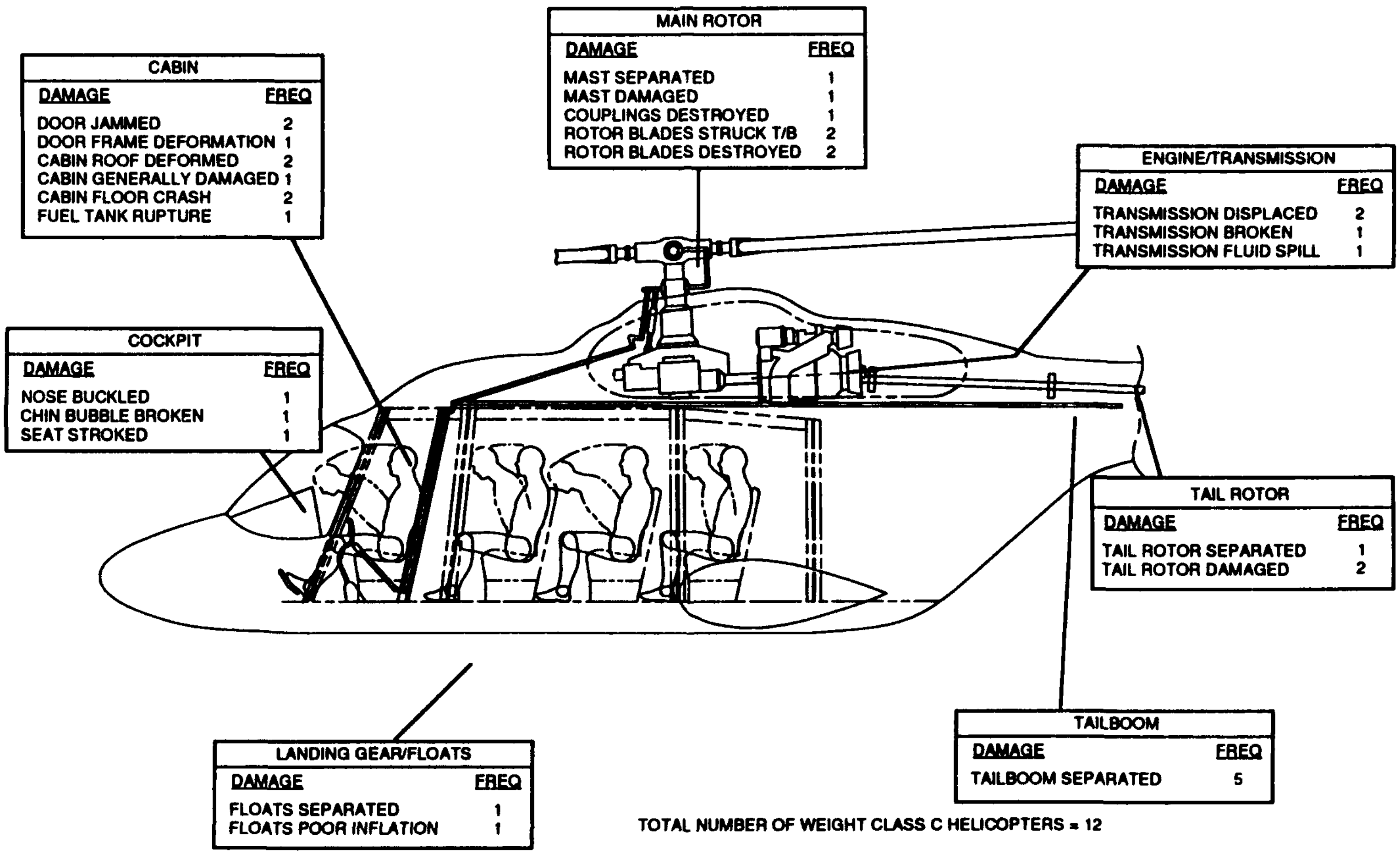



FIGURE 6. SUMMARY OF IMPACT DAMAGE FOR WEIGHT CLASS C ROTORCRAFT

Engine/Transmission — Transmission displacement was noted but did not penetrate the occupiable volume. The spillage of transmission fluid was not reported to have caused any injury.

Landing Gear and Floats — Separation and inflation problems with rotorcraft flotation equipment was noted.

Main Rotor — The mast and main rotor blades were damaged but this damage was not a contributor to injury.

Tail Boom/Tail Rotor — Separation of the tail boom occurred frequently and occurrences of tail rotor damage were also noted. This damage was not reported to contribute to injury of occupants.

## 5.4 SUMMARY OF ROTORCRAFT STRUCTURAL DAMAGE.

The same types of damage were noted for both weight classes of rotorcraft. The tail boom/tail rotor and the main rotor were found to frequently separate upon impact. Breakage of the windshield and chin bubble were also frequently noted. Damage types observed with the potential to significantly affect occupant injury were:

a. Transmission displacement,
b. Cabin deformation,
c. Seat separation, and
d. Door jamming/door frame deformation.

These damage types, however, were generally not reported to have occurred either frequently enough or with enough severity to have had a significant effect on occupant survivability.

## 6. INJURY ALLEVIATION.

In previous sections, airframe and component modes of failure and their effects on occupant injury were discussed. In this section, potential means to alleviate the injuries resulting from water impacts are identified. The injuries discussed are those related to survivable and significant survivable water crashes. Recall that in only a few cases was it evident that impact injuries contributed to post-impact fatalities. Therefore, alleviation of injuries in water related accidents appears to be separated into two distinct efforts. Thus, the injuries are divided into two broad categories: injuries sustained in the major impact of the rotorcraft onto the water surface; and injuries sustained in the post-crash environment.

## 6.1 WATER IMPACT INJURIES.

Compromise of the occupiable volume and penetration of occupiable volume (by water) were found to cause injuries during water impacts; however, these injuries predominantly occurred in the nonsurvivable class of water impacts. The types of injuries sustained in survivable and significant survivable water impacts were found to be grouped into distinct anatomical regions. These injuries are those that should be targeted for alleviation and include:

a. Spinal compression injuries caused by excessive whole-body acceleration,
b. Head and face injuries caused by flailing,
c. Upper torso injuries caused by flailing,
d. Upper extremity injuries caused by flailing, and
e. Lower extremity injuries caused by flailing.

These injury types are caused by whole-body acceleration and occupant flailing. As noted in section 4., the injuries sustained in water impacts are distributed somewhat uniformly regardless of the rotorcraft weight class and occupant location in the rotorcraft. Potential means to alleviate these types of injuries are discussed.

6.1.1 Energy-Absorbing Seating Systems.

The alleviation of spinal compression injuries in helicopter crashes has been the goal of substantial research, development, and production of energy-absorbing seating systems. These efforts have resulted in numerous rotorcraft models being equipped with such seating systems. Sufficient field experience (predominantly U.S. Army) has demonstrated that these seating systems reduce the incidence of spinal injury. Furthermore, in water impacts, energy-absorbing seating systems have been shown to provide benefits to the occupant similar to those realized in land impacts. Additionally, a few such seating systems are currently in service in the civil rotorcraft fleet. In the rotorcraft so equipped, available accident data indicates that benefits are realized with stroking seats. Detailed information concerning the design and qualification of energy-absorbing seating systems may be found in Volume IV of the U.S. Army Crash Survival Design Guide (reference 3). Specific performance criteria for civil rotorcraft seating is found in Parts 27 and 29 of the FARs.

As noted in earlier sections, occupants experiencing spinal compression injuries were seated in both the crew and passenger areas. Thus both the crew and passenger seating should control loads to occupant and absorb kinetic energy in a crash.

To properly function, an energy-absorbing crew seat should have a minimum of a four-point restraint (five-point is preferred). The restraint will have two purposes; to hold the occupant's spine in line with the stroking direction of the seat; and to prevent upper body flailing which will be discussed later. For the same reasons, the passenger seats should be equipped with a minimum of three-point restraint systems. For side-facing seats, three-point restraints should have the shoulder harness anchor oriented toward the front of the rotorcraft.

6.1.2 Enhanced Upper Body Restraint.

This section assumes that the occupant already has adequate lower torso restraint. As indicated, a significant number of injuries occur to the upper torso, head, and face. A primary means to alleviate these injuries is to provide enhanced upper torso restraint.

Adequate upper torso restraint, required for proper function of energy-absorbing, load limiting seating systems, will aid in preventing the occupant from striking the instrument panel, cyclic control stick, rotorcraft structure, other seating, etc. However, accident data and numerous crash testing programs have shown that even with proper upper body restraint, an occupant may still strike the rotorcraft structure and interior components. Thus, although upper body restraint is vital, the design should consider supplemental concepts (e.g. delethalization of the occupant environment) as well ensure alleviation of injuries.

It is possible that for some applications, the Inflatable Body and Head Restraint System (IBAHRS) could be applied to the restraints of the crew seating systems. The IBAHRS (reference 4) consists of two air bags that inflate underneath the shoulder harnesses to reduce the excursions of the occupant during a crash. When a crash sensor detects a crash pulse above a set threshold, two gas generators are fired which inflate the airbags. The IBAHRS is currently being developed and fielded for U.S. Army and Marine Corps Cobra helicopters. The U.S. Army is also conducting research on other inflatable restraint devices that may ultimately have application to civil helicopters.

6.1.3 Protective Gear.

Helmets, perhaps, offer the most effective means of preventing head injury. The use of helmets by military aviators significantly reduces the number and severity of head injuries. Further, military experience indicates that the added weight of a helmet does not appear to increase the likelihood of neck injury. However, the use of a helmet should be accompanied by provision of a head rest to reduce the possibility of whiplash type injury. Numerous minor injuries, such as lacerations and abrasions, can be alleviated by using gloves and heavy (tear resistant) clothing or flight suits.

6.1.4 Delethalization of Environment.

General delethalization of the occupant environment (flailing envelope) offers the means to alleviate a significant number of the flailing injuries to the head, upper torso, and upper and lower extremities. Several delethalization methodologies should be considered. They include moving components out of the occupant flailing envelope, installing energy-absorbing padding or foam onto interior components, using frangible materials and designs in the production of interior components, and geometrically designing the interior of the rotorcraft to preclude injuries. More information may be found in the U.S. Army Crash Survival Design Guide, Vol IV (reference 3).

Components within the flailing envelope of an occupant should be considered for relocation if possible. If a component may not be moved out of the envelope, it should be considered for delethalization. An example would be the door frame. Since its position is fixed, it should be softened with energy-absorbing padding or foam to reduce the likelihood of injury should an occupant strike it. Another location that padding would result in benefits is the underneath side of the instrument panel. Numerous leg fractures and other lower extremity injuries could be alleviated by the use of padding in this area (figure 7).

FIGURE 7. LOWER LEG STRIKE ENVIRONMENT FOR PILOT AND COPILOT

Other areas requiring delethalization may not be able to accommodate a padded surface or a padded surface may not provide sufficient delethalization. An example would be the instrument panel glare shield in which padding could cause difficulty in viewing gauges. A typical current instrument panel (figure 8). If occupant strike is anticipated to be a problem, the panel may be of frangible design so it will break before the occupant strike causes severe injury. Additionally, gauges and switches should be mounted flush with the panel to preclude severe facial injury should a strike occur.

The cyclic control stick is an example of a component where padding and frangible design are both suggested. The cyclic control stick has traditionally been a significant strike hazard in rotorcraft (figure 8). With the introduction of energy-absorbing seats, the hazard has increased. Research has been conducted to delethalize the cyclic stick by padding the stick and allowing it to break free at the yoke attachment when struck in a crash (figure 9). The force required to separate the stick is just under the fracture tolerance of the human skull (reference 5).

FIGURE 8. TYPICAL CURRENT INSTRUMENT PANEL

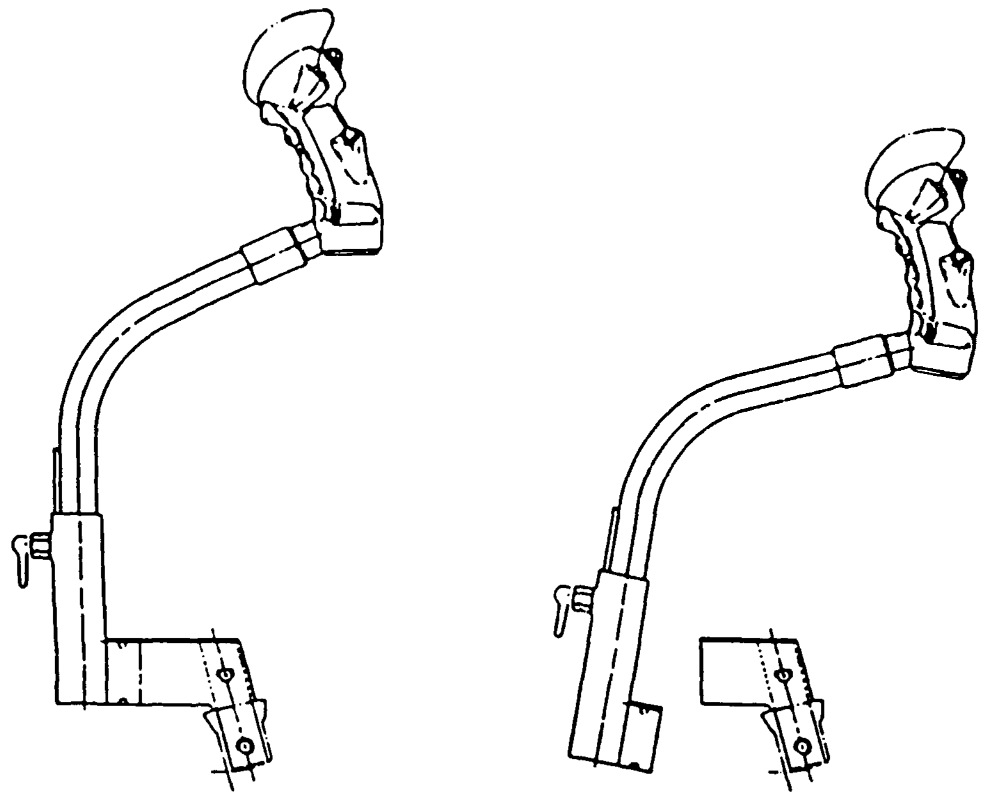
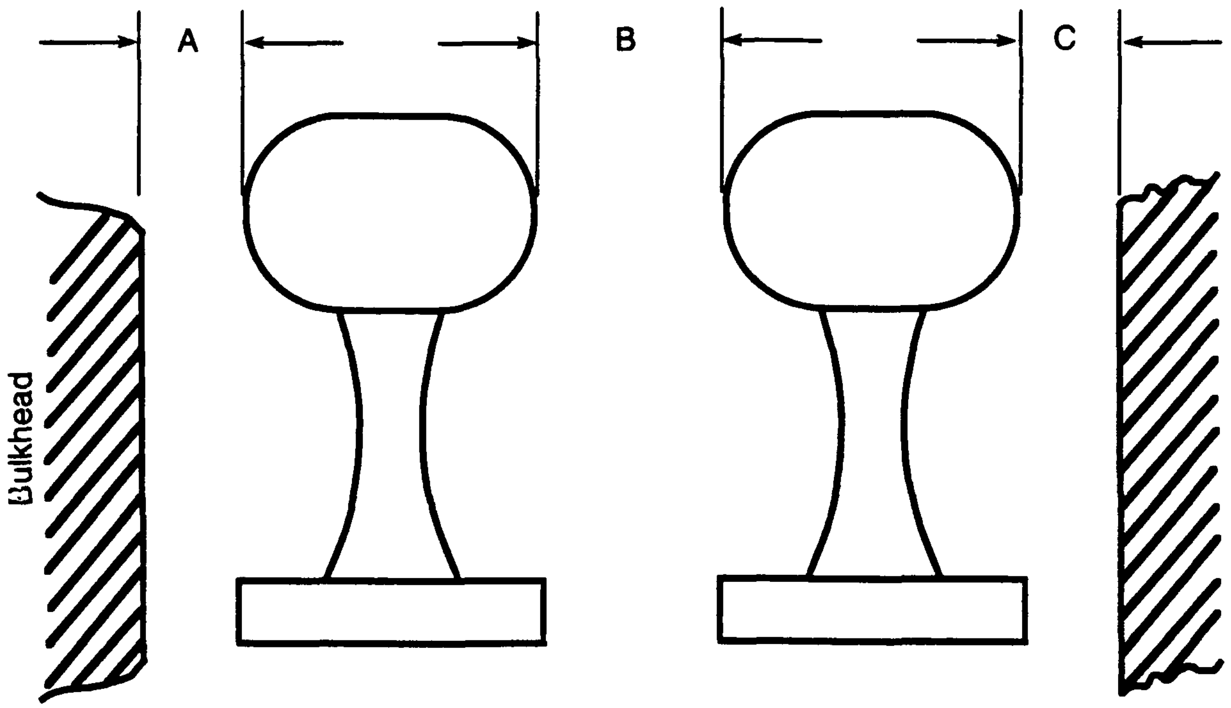


FIGURE 9. DELETHALIZED CYCLIC CONTROL STICK (REFERENCE 4)

A final methodology involves designing interior components so they will not injure occupants. An example would be the rudder pedals. They should be designed to preclude the occupant's ankle from being pushed underneath the pedal as can happen with simple bar type rudder pedals. The spacing of the pedals and their relative location with respect to other cockpit components should be such that the occupant's foot will not become entrapped during an impact. Entrapment is especially serious in a water impact accident because of the high probability of rotorcraft overturning. A diagram of preferred rudder pedal design and configuration (figure 10) (reference 3).




Dimensions A, B, and C must be either less than 2 in. or more than 6 in.

FIGURE 10. ANTITORQUE (OR RUDDER) PEDAL GEOMETRY TO PREVENT ENTRAPMENT OF FEET (REFERENCE 4)

## 6.2 POST IMPACT INJURIES.

Overwhelmingly, the post impact injury type that needs to be addressed is drowning or suffocation due to water inhalation. In nearly every instance of drowning, inadequate flotation was a contributing factor. The other primary factor was the failure of the occupant to properly egress from the rotorcraft. Alleviation of post impact drowning should be accomplished through alleviation of the contributing factors which is the focus of this section.

6.2.1 Rotorcraft Flotation.

In Phase I (reference 1), it became apparent that it is rare, in a water impact, when the rotorcraft remains upright for a significant length of time. Furthermore, the rotorcraft flotation equipment is frequently damaged or separated during the impact, a result that is more likely when the floats are inflated prior to impact. Separation of inflated floats occurred more frequently with skid mounted than with fuselage mounted devices. Separation of the floats from the rotorcraft was also shown to contribute to post-impact drowning in several cases. Thus, a water sensor or other triggering devices should be considered to initiate the inflation of the floats upon impact with the water.

The optimal situation is for the floats to maintain the rotorcraft in an upright position following impact. However, wave action and the inherently high center of gravity of rotorcraft frequently cause overturning. A significant longitudinal or lateral velocity also contributes to overturning. This effect is often increased if the floats are deployed prior to impact.

6.2.2 Life Rafts.

Life rafts were not used in the majority of the life raft-equipped rotorcraft water impacts investigated in the Phase I program. This is a result of several factors. Life rafts stored near the chin bubble are often lost when water blows out the chin bubble. The rapid overturning of the rotorcraft requires occupants to egress immediately rather than locate the life raft then egress. The effects of wave action on the floating helicopter often precludes reentry for the purpose of extracting the life raft. Reentry is not advisable with current systems because of the frequency of delayed separation of the floats from the rotorcraft. Access to the life raft should be improved in the common event of an overturned helicopter. Locations to consider include exterior of the rotorcraft, exterior access panels, near the rotorcraft floor by an exit, and integrated with the flotation system.

6.2.3 Personal Flotation.

Personal flotation devices were often used in the accidents examined in Phase I (reference 1). The majority of the devices used were inflatable. They were reasonably effective for occupants who were wearing the devices and knew how to use them when the impact occurred. However, after some time in rough seas, the flotation devices often developed leaks. Occupants also became fatigued due to continual manual inflation of the devices. Life vests should be designed to provide sufficient flotation for several hours in rough seas. A significant problem was that the personal flotation devices were not often worn while in flight. The rapid overturning of the rotorcraft then precluded the occupants from locating and donning their life vests.

6.2.4 Exposure Protection.

A noted problem was the lack of exposure protection when egressing into cold water. Either an accessible life raft and/or suitable exposure protection should be provided when operating over cold waters. The type(s) and level of exposure protection should be based on the anticipated water temperature and time to rescue.

6.2.5 Preflight Briefing.

Comments were encountered in the Accident Reconstruction portion of Phase I (reference 1) such as "I didn't know I was supposed to put my legs in those straps." Quite often, ignorance of proper procedures contributed to drowning. In other cases, occupants were found to have had lap belt buckles inverted and thus were not able to release the belt with the rotorcraft inverted. Thus, the preflight briefing should be accompanied by a safety check, similar to the Part 25 rotorcraft preflight procedures.

6.2.6 Fuel Containment.

The incidence of post-crash fire was not noted in reference 1. However, in at least two of the survivable accidents, considerable fuel spillage occurred. The floating fuel resulted in chemical burns to occupants and a significantly increased potential for post-crash fire. Thus, crash resistant fuel systems are recommended.

## 7. REVIEW OF ANALYTICAL METHODS - WATER IMPACT.

Discussion of the damage mechanisms involved in rotorcraft water impacts illustrates the factors that must be accounted for in an analytical model. There have been two main mechanisms observed in rotorcraft water impacts that damage the structure, one imposed by vertical impact loads and one imposed by drag loads. These two mechanisms are both present to a varying degree in all water impacts. The degree to which they are involved is dependent on the impact conditions. Two of the impact scenarios defined in reference 1 were: predominantly vertical impacts, and longitudinal impacts. These two sets of impact parameters represent the two extremes that have been observed. The way in which the two damage mechanisms act in these two impact scenarios can be seen in the following discussion.

In predominantly forward velocity impacts with low vertical velocity the rotorcraft tends to slide along the water surface with relatively low accelerations. However, several factors can alter rotorcraft behavior. Failure of lower fuselage skin panels can expose interior structure such as bulkheads. The hydrodynamic drag induced by this damage can significantly increase the deceleration of the rotorcraft. Exposed landing gear structure also increases the drag load. which increases the downward pitching tendency of the rotorcraft begun by drag forces on the forward structure (reference 6).

Impacts with high vertical velocities and relatively low longitudinal velocities demonstrate the difference between rigid surface impacts and water impacts. The impact force is distributed over the entire contact surface in a water impact which can place excessive loads on the fuselage skin panels. Failure of these skin panels then exposes the interior structure and floor of the rotorcraft to vertical hydrodynamic forces that may induce bending in longitudinal members. From this damage description it can be seen that energy absorption by the fuselage may not occur in water impacts to the same extent as it occurs in rigid surface impacts (reference 6).

Analytical models should be capable of accurately modeling these failure mechanisms to be useful analytical tools. The discussion of currently available methods will focus on adequate simulation of these mechanisms. Also to be considered is the type of model the analytical method uses to represent the rotorcraft structure.

## 7.1 KRASH.

### 7.1.1 Program Summary.

Program KRASH is a computer model that uses lumped masses and massless interconnecting structural elements to represent rotorcraft structure. The program output includes the nodal mass displacements, velocities, and accelerations, as well as any structural failures that occur as a time history of the impact. It has been validated and used to model impacts on rigid surfaces. Recently, under sponsorship by the Federal Aviation Administration (FAA) with support from the Naval Air Development Center (NADC), KRASH was updated with an algorithm to model water impacts. Although work on this algorithm is ongoing, its highlights are described in this section. The information on the KRASH water impact algorithm was taken from reference 6.

### 7.1.2 Water Modeling Capability.

The water impact algorithm developed for program KRASH utilizes two models to simulate the damage mechanisms identified for water impacts. These two models can be summarized as follows:

a. Planing Surface Model — This model accounts for the predominantly vertical loads imposed by impact with the water. The planing surface model theory assumes that the rotorcraft's impact momentum is transferred to a virtual mass of water where some momentum is shed as a wake. This model is represented in program KRASH as a horizontal surface fixed to the rotorcraft model by a rigid link. The mass of the planing element is varied as contact with the water varies so that the mass of the rotorcraft is distributed proportionally to all planing elements in contact with the water. This method models the virtual mass concept of momentum transfer.

b. Hydrodynamic Drag Surface Model — This model accounts for the drag force created by vertical surfaces moving through the water, such as landing gear and exposed bulkheads. Program KRASH represents this model by applying the hydrodynamic force normal to the submerged drag area of each model element at its centroid.

These two models are combined in a new hydrodynamic element defined for KRASH, each of which contains a planing surface and a drag surface. The failure criteria for each hydrodynamic element, such as bursting pressure for planing surfaces, are defined as program input. Then, when the program is run, the failure criteria is used to determine when a planing surface has failed. Failure of a planing surface then exposes the drag surface part of the hydrodynamic element to drag forces generated by the water. This process simulates the bursting of rotorcraft skin and the exposure of interior bulkheads to hydrodynamic forces. The forces determined in this way are then transmitted to the rest of the airframe.

7.1.3 Discussion of Capabilities.

Although evaluation results of the water impact algorithm were favorable, they demonstrated some areas that could be improved. The water impact algorithm for program KRASH has been evaluated only for the case of high longitudinal velocity and slight nose up pitch. The airframe response in the KRASH representation of a longitudinal impact was similar to the accident data it was compared to with some differences. The response of the cockpit of the KRASH model differed from the accident data by remaining attached to the airframe and continuing to submerge as the rotorcraft pitched forward. One possible reason for this is that the planing forces are lost once the planing surface fails. Therefore, these vertical forces are no longer accounted for and the load on the structure is not represented accurately. Further evaluation of the code, with a vertical velocity accident case, is planned. Additionally, the code will be refined to incorporate lessons learned from the evaluations and the program's output features will be enhanced.

7.2 METHODS OTHER THAN KRASH.

A review of analytical methods other than KRASH was conducted to assess applicability of the methods to address helicopter water impact. Several codes were identified that might be applicable, however, none were found to be more suitable than KRASH.

Accurate simulation of the water impact problem involves two fundamental solutions. The first is the solution to the fluid mechanics problem of rotorcraft striking the water. The second is the problem of the highly nonlinear structural response of the rotorcraft during the water impact. These two problems (at least) must be solved simultaneously to provide accurate simulations of water impacts. Several available computer codes exist to do one or the other (i.e. DYNA3D, PISCES, PAM-CRASH); however, a computer code that will accomplish both in the same simulation was not identified. It is anticipated that such a code would be expensive to develop and maintain. If the development were completed, the primary usage would likely be in the research environment as it would presumably would not be cost effective to use as a routine design tool.

It is believed likely that the finite element program DYCAST (reference 7) could support modification to roughly approximate the water impact problem much in the same way that program KRASH has been modified. The resulting computer code would be expected to have a more detailed structural response than would be given by program KRASH.

## 8. CONCLUSIONS.

a. The main occupant injuries suffered in water impacts were from flailing and excessive acceleration resulting from occupant interaction with the rotorcraft interior and insufficient structural energy absorption.

b. Drowning and exposure were the main post-impact hazards. Other post-impact injuries were minor in severity. Impact injuries infrequently impaired post-impact survivability.

c. Structural failures of the rotorcraft were not found to be significant contributors to occupant injury. The occupiable volume was generally preserved intact in the cases examined.

d. The performance of rotorcraft flotation equipment, as is currently deployed and used, does not adequately keep the occupiable area of the downed rotorcraft upright and afloat.

e. The techniques to alleviate injuries sustained in water impacts are similar to the techniques required to alleviate injuries sustained in rotorcraft accidents occurring on other terrain.

f. Techniques for alleviating occupant injury in rotorcraft water impacts include: better occupant restraint, delethalization of the cockpit and cabin interior, energy-absorbing seats, improved performance and use of personal flotation devices, and improved performance of rotorcraft flotation equipment.

g. Analytical modeling the water impact of a rotorcraft is being evaluated.

## 9. REFERENCES.


1. "Rotorcraft Ditchings and Water Related Impacts that Occurred from 1982 to 1989 — Phase I," U.S. Department of Transportation, Federal Aviation Administration Technical Center, DOT/FAA/CT-92/13, December 1992.

2. Coltman, J. W., Bolukbasi, A. O., and Laananen, D. H., "Analysis of Rotorcraft Crash Dynamics for Development of Improved Crashworthiness Design Criteria," U.S. Department of Transportation, Federal Aviation Administration Technical Center, DOT/FAA/CT-85/11, June 1985.

3. Desjardins, S. P., Zimmermann, R. E., Bolukbasi, A. O., and Merritt, N. A. "Rotorcraft Crash Survival Design Guide, Volume IV — Rotorcraft Seats, Restraints, Litters, and Cockpit/Cabin Delethalization," U.S. Army Aviation Research and Technology Activity (AVSCOM), USAAVSCOM TR 89-D-22D, December 1989.

4. Mcelhenney, J.R., "IBAHRS — An Inflatable Restraint System for Helicopter Aircrew Members." Naval Air Development Center, Report No. NADC-82046-60, February 18, 1992.

5. Whitaker, C.N., and Zimmermann, R.E., "Delethalized Cyclic Control Stick." Simula Inc, Report No. USAAVSCOM TR-86-D-3, Aviation Applied Technology Directorate, U.S. Army Aviation Research and Technology Activity (AVSCOM), Fort Eustis, VA 23605-5577, July 1986, AD A173931.

6. Wittlin, Gil, "KRASH Water Impact Code Update" (draft final report), for Galaxy Scientific Corporation, July 26, 1991.

7. Pifko, A.B., Winter, R.E., and Ogilvie, P.L., "DYCAST — A Finite Element Program for Crash Analysis of Structures," National Aeronautics and Space Administration, NASA-13148, 1982.

8. "The Abbreviated Injury Scale 1980 Revision," American Association for Automotive Medicine, 1981.

9. "Airworthiness Standards: Normal Category Rotorcraft." Part 27, Chapter I — Federal Aviation Administration, Department of Transportation, Title 14 — Aeronautics and Space, Code of Federal Regulations.

## 10. GLOSSARY.

Abbreviated Injury Scale (AIS) — A set of terms used in this study to define injury severity which was developed by the American Association for Automotive Medicine (reference 8).

Attitude — Angles describing the orientation of the rotorcraft relative to the mutually perpendicular rotorcraft axes. See figure 11.

Ditching — An emergency landing on the water, deliberately executed, with the intent of abandoning the rotorcraft as soon as practical. The rotorcraft is assumed to be intact prior to water entry with all controls and essential systems, except engines, functioning properly (reference 9).

Nonsurvivable Accident — No portion of the cockpit or cabin met the definition of survivable.

Partially Survivable Accident — Some portion of the cockpit or cabin met the definition of survivable (reference 2).

Significant Survivable Accident — The accident was judged to be either survivable or partially survivable and one or more occupants received impact injuries.

Survivable Accident — The acceleration environment was within the limits of human tolerance, and a sufficient occupiable volume remained for properly restrained (lapbelt and shoulder harness) occupants, with the effects of fire not considered (reference 2).

Velocity Components — Velocity vectors oriented along the mutually perpendicular longitudinal, vertical, and lateral axes of the rotorcraft. See figure 11.

Water Impact — Any impact with water, in which the pilot may have had varying degrees of mechanical control of the rotorcraft.

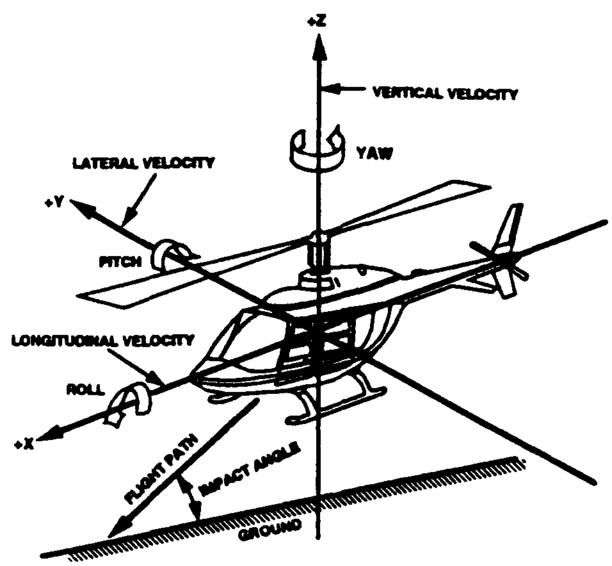



FIGURE 11. HELICOPTER ATTITUDE AND VELOCITY COMPONENT DIRECTION

# APPENDIX A - GENERIC ROTORCRAFT LAYOUTS

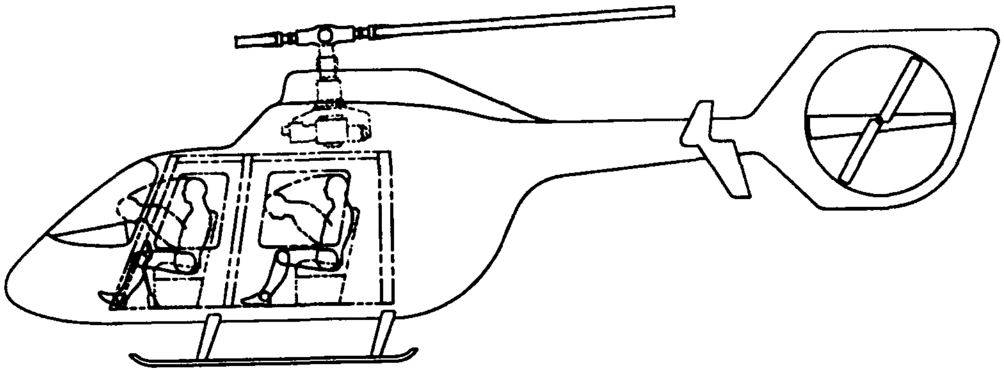


FIGURE A-1 GENERIC ROTORCRAFT LAYOUT SIDE VIEW — WEIGHT CLASS B

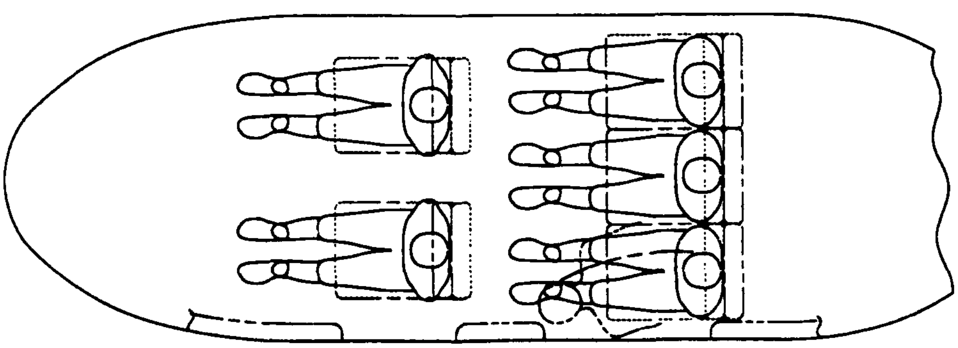


FIGURE A-2 GENERIC ROTORCRAFT LAYOUT TOP VIEW — WEIGHT CLASS B

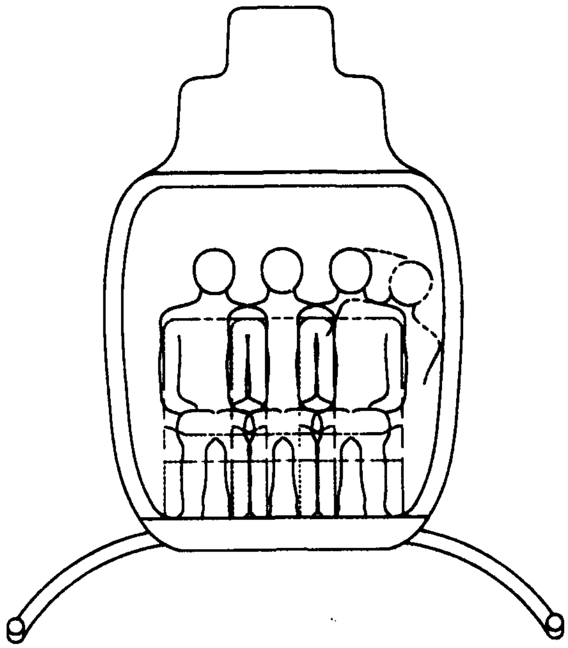


FIGURE A-3 GENERIC ROTORCRAFT LAYOUT FRONT VIEW — WEIGHT CLASS B

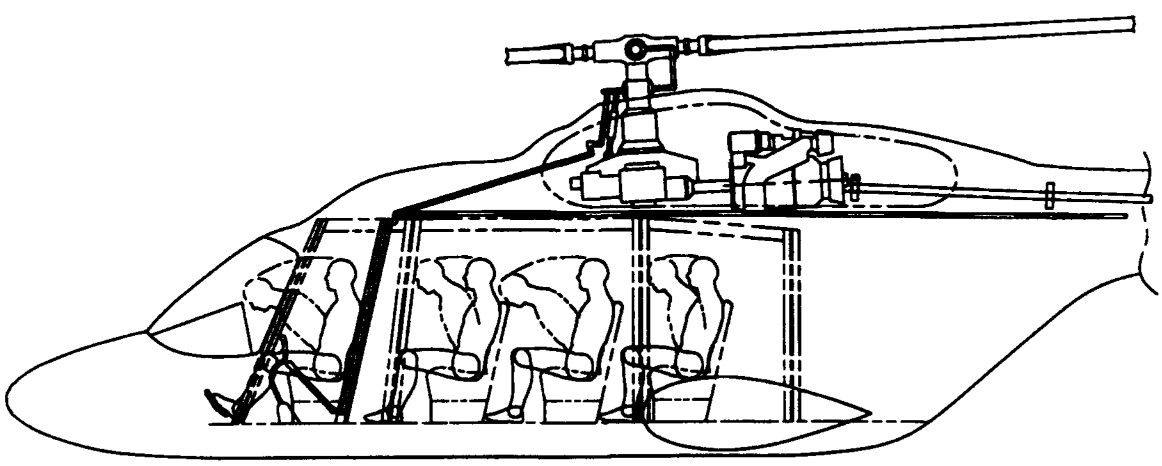


FIGURE A-4 GENERIC ROTORCRAFT LAYOUT SIDE VIEW — WEIGHT CLASS C

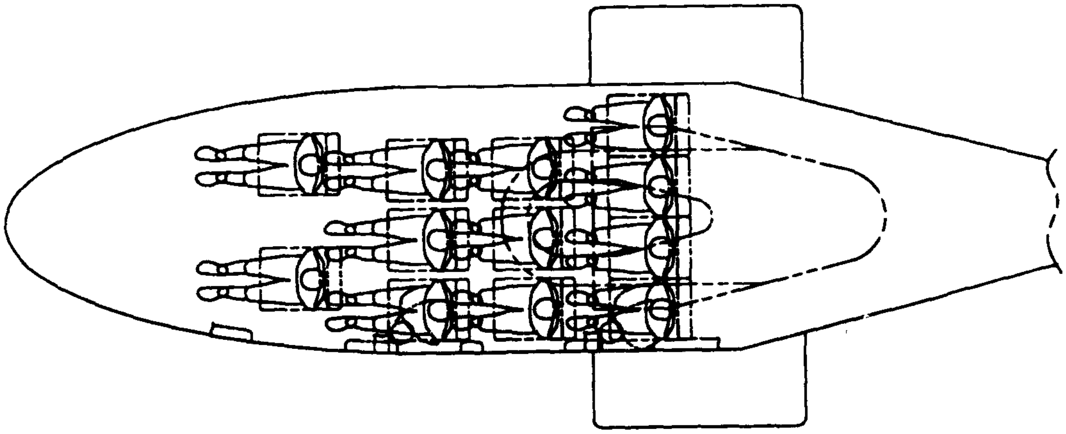


FIGURE A-5 GENERIC ROTORCRAFT LAYOUT TOP VIEW — WEIGHT CLASS C

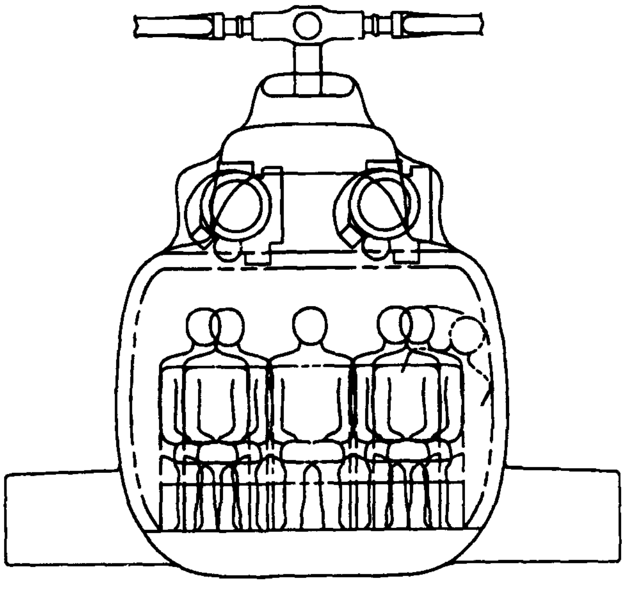


FIGURE A-6 GENERIC ROTORCRAFT LAYOUT FRONT VIEW — WEIGHT CLASS C



☆U.S. GOVERNMENT PRINTING OFFICE: 1994 - 504-078/80241