Fatal Injuries Resulting from Extreme Water Impact

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Increased overwater flight has resulted in an increase in both military ejections and civil crash landings in water, 78 general aviation water accidents occurring last year. The objective of this study was to determine mechanisms of gross trauma in non-penetrating fatal water impact. The method involved analysis of necropsy data on 169 fatal (52 female, 117 male) jumps from the Golden Gate Bridge. Impact velocities ranged from 106-112 ft/sec (32.31-34.14 m/sec) and body orientation was mainly transverse ($\pm$ G_x) or lateral ($\pm$ G_y). The most common mechanism of injury was crushing of the thoracic cage with resultant bilateral rib fractures and penetration of the vital organs (85.2 per cent). Lung lacerations, ruptured livers, brain injury, and drowning were most frequent. In 17 cases, no skeletal fractures were found. Eight individuals, apparently relatively uninjured by the impact ($\pm G_z$?) subsequently drowned. These data reinforce previous work indicating human tolerance in water impact close to 116 ft/sec (33.53 m/sec) velocity, and that body orientation is critical. Additional protection in transverse and lateral impact must be considered for increased survivability.

CURRENTLY IT IS ESTIMATED that one-third of all commercial air transportation involves flight over a water environment. It is becoming increasingly common for private civil aircraft to fly water routes as aircraft range, performance, and navigational and survival equipment improves. Due in great part to the less hostile conditions of impact in water as compared to terrestrial environments, all United States manned space flights to date have re-entered in "splash-downs."

Accompanying this increased overwater activity is an increased risk and incidence of crash landings.[14] Military aircrew ejections, for example, into water are occurring with much greater frequency under low-level, high or terminal velocity conditions. In manned space-flight, the 13.7 meters per second estimated descent rate of the Apollo capsule with a damaged parachute would probably be injurious to occupants in a ground landing.[13] In civil aviation in the United States last year alone 78 general aviation accidents occurred in water.[2]

Since little is known concerning human survival tolerances in water impacts, design of an optimum protection and survival envelope is largely dependent upon rather meager knowledge of basic human biological tolerances. The objective of this study has been to evaluate fatal trauma and determine primary causes of death in impact with a water surface. Information relating to the total envelope of survivability criteria supplements previous free-fall survival data obtained in water impact research.[11]

METHOD AND MATERIALS

The 169 cases reported in this study involved suicides in jumps from the Golden Gate Bridge in San Francisco for which autopsies were available during the 28-year period from 1937 to 1966. This bridge provides a unique experimental situation as far as extreme impact is concerned. Since its construction in 1935, California Highway Patrol records officially show that 305 persons, as of 10 August 1966, have jumped from it. However, the actual figures may be much higher since bodies can usually be recovered only during daylight hours. Thus, a person might jump at night undetected

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and never be recovered. To prevent this, the bridge is now closed to pedestrian traffic during the hours of darkness. At present, the chances for survival of a jump from this bridge are not good: 99.3 per cent of the known falls have been fatal. To date, the only survivors have been a 28-year-old female who jumped in 1941, and a 16-year-old boy, who jumped in January of this year, both impacting in water. Two others survived for 10 hours and 10 days.[10]

The present series does not include survivors, those who impacted on surfaces other than water, or those whose bodies were unrecovered or were recovered by other than San Francisco County. In addition, cases were not included if injuries were obviously caused by impact with floating objects or the base of the pier adjacent to the Bay.

Such free-fall data have several useful advantages over similar information obtained from typical aircraft or automotive accidents because environmental factors can be ascertained with greater confidence. Accidents in which the individual may be displaced several times during the impact sequence are difficult to analyze. On the other hand, in the present series, a number of parameters are constant throughout. Each individual impacted a water surface; the distance, and thus velocity at impact were nearly identical; and each case included complete CHP reports (including witness statements). Complete gross and microscopic necropsy was performed by the San Francisco Coroner's Office on each case presented here. One unknown factor was direction of force. However, examination of the trauma in each case provided good indications as to body orientation at impact, the majority of these cases being in a combination of transverse or lateral $\pm G_{x,y}$ positions.

Until the recent completion of New York's Verrazano-Narrows Bridge, this structure was the longest suspension span ever constructed, with a 4200′ single center span conjoined by two 1125′ side spans at 746-ft steel towers.[8] Vertical clearance under the center of the bridge is 220′ at high water level, and the roadway, resting on steel stiffening trusses, is 25′ higher, with sidewalks along the roadway guarded by 4-foot steel railings. At the mid-span the distance from rail to water is 249′ and about 261′ at low tide. On either approach the clearance is 10′ less. Some individuals have jumped from the chord, a flat steel support structure which extends 4′ out on either side and 8′ below the railing level. Thus, each of the jumps included in this study involved distances exceeding 239′ and ranging to 261′. Velocity in free-fall is calculated as $V = \sqrt{2gS}$, where g (at San Francisco) = 39.49 meters per second, and S or distance = 37.19 to 38.04 meters per second velocity. Utilizing the aerodynamic drag correction of Cotner[3] and Earley,[4] these velocities were calculated to range closely between 32.92 to 33.53 meters per second (or 73.6 to 75 mph) impact force in each case. Wind, a strong tide, and waves add to the hazards of the jumper. In analysis each case history was examined and rechecked by the authors at least three times, and statistical data reduced and correlated by means of a Royal Keydex retrieval system.

RESULTS

Necropsy reports were examined for 169 individuals (52 female and 117 male) who had received fatal trauma as a result of water impact in jumps of 32.92 to 33.53 meters per second impact velocities (239-250′) from the Golden Gate Bridge in San Francisco.

To provide information concerning age distribution of the sample, age groups of five-year periods were made, with those under age 25 lumped at one end, and those age 65 or older at the other extreme. (Figure 1) The table shows good distribution with a slight increase in cases with each subsequent age group. Only 10 cases occurred (5 female/5 male) under age 25, but 25 individuals (22 males/3 females) were over age 64. Except for the late 30's male and female distribution were similar up to age 50, after which all age groups were predominately male. There was a high predominance of male suicides at the older age levels.

Body weights for each sex are tabulated in Table I. There appears to be a relatively normal spread considering the ages involved and fact that some of the older males were in ill health.

HEART AND GREAT VESSELS

Of the 169 autopsies, 87 (50.9 per cent) displayed significant cardiovascular trauma ranging from contusive injuries to frank disruption of major vessel or chamber. Only 5 of the 87 failed to display multiple

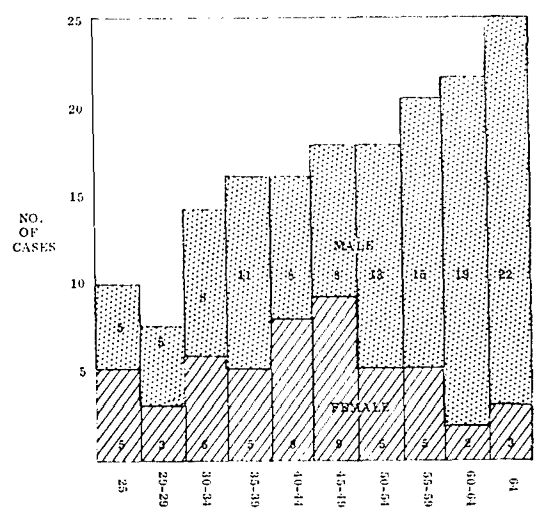

Fig. 1. Age and sex distribution.

TABLE I. BODY WEIGHTS OF FATAL IMPACT CASES

Weight (in lbs.)	Female	Male
>200	—	5
190 – 199	1	6
180 – 189	—	15
170 – 179	2	15
160 – 169	3	14
150 – 159	8	16
140 – 149	4	13
130 – 139	16	17
120 – 129	4	6
<120	11	3

fractures of the bony thorax. Such fractures are generally described as penetrating the pleural and/or pericardial cavities and, in most instances, one or both lungs are lacerated at sites corresponding to the parietal disruption. It is therefore probable that the majority of the injuries sustained by the heart and great vessels are also due to penetration by broken skeletal elements rather than to rupture from within the vessel due to sudden increase in pressure.

Forty-two cases were reported in which one or more chambers of the heart were ruptured. Twenty-seven individuals showed damage to only a single chamber, the remainder suffered ruptures of two or more chambers. The left atrium appears to be the chamber most vulnerable to damage. (Table II) In addition to the 42 cases with frank rupture of the heart, an additional ten were encountered which showed moderate to severe cardiac contusions, bringing the total number with damage to the heart to 52.

Traumatic rupture or laceration of one or more of the great vessels was found in 45 cases, 12 of which were associated with cardiac rupture. Within the series of 45 cases, 11 displayed rupture of two or more vessels to give a total of 67 lesions observed. In severity, these cases range from a small tear in a single vessel to an instance where all major vessels were severed from the base of the heart and the heart itself avulsed through the pericardium to lie free in the body cavity. In terms of frequency, aortic ruptures were the most common, a total of 38 such lesions being reported, 22 of which occurred in the ascending aorta, two in the arch and 14 in the descending aorta. The other 27 vessel disruptions were distributed among the other great vessels with tears of the vena cava most frequently found. A more detailed analysis of the frequency and location of injuries is given in Table III.

Comparison of the 86 significant cases of cardiovascular trauma which was found in this study with the 459 such cases from the files of the Armed Forces Institute of Pathology reviewed by Gable and Townsend, supports their findings concerning differences between blunt and penetrating fatal trauma.[6] Aortic ruptures appear to be the most common type of injury in both studies, with roughly one-fourth (42 cases) of our water impact cases receiving one or more chambers of the heart ruptured, and rupture or laceration of one or more of the great vessels (45 cases). While it has been demonstrated elsewhere that direct nonpenetrating cardiac trauma seldom produces serious consequences unless the myocardium ruptures or a fatal arrhythmia develops, the consequences of penetration of the thoracic area by numerous ragged sharp rib and sternal fragments are obviously considerably more traumatic.

RESPIRATORY SYSTEM

In 131 cases, the lungs or trachea were injured, with penetration of at least one lobe being due to jagged rib fractures in 129 cases or 76 per cent of these impacts. The lungs were the most vulnerable organ due to this high incidence of rib penetrations.

DIGESTIVE SYSTEM

Injuries to the digestive system occurred in nearly half of these water impacts, with 91 out of 96 such injuries occurring to the liver. Virtually all of these injuries could be attributed to lacerations of lobes of the liver due to rib fractures. Four ruptures of the small intestine itself, two of the stomach, and one of the large intestine were also found. In one case, hemorrhage extended into the pancreatic capsules, and in a second hemorrhage in the retroperitoneal spaces and mesentery occurred around the pancreas.

Hemorrhage or laceration to the adrenal glands was observed in only five instances.

TABLE II. AN ANALYSIS OF 42 CASES OF HEART RUPTURE

One Chamber Ruptured:	No. of Cases:
RA	6
LA	15
RV	2
LV	4
Two Chambers Ruptured:	
RA + LA	3
RA + RV	1
RA + LV	0
LA + RV	2
LA + LV	1
RV + LV	3
Three Chambers Ruptured:	
RA + LA + RV	0
RA + LA + LV	2
RA + RV + LV	0
LA + RV + LV	0
All Chambers Ruptured:	
RA + LA + RV + LV	3
TOTAL CHAMBERS RUPTURED	
RA: 15 LA: 26 RV: 13 LV: 11	

TABLE III. SITE OF RUPTURE IN 45 CASES OF TRAUMA TO GREAT VESSELS

SINGLE LESIONS:	No. of Cases
Aorta	
Ascending Aorta	11
Arch	1
Descending Aorta	8
Pulmonary Artery	2
Pulmonary Veins	3
Superior Vena Cava	1
Inferior Vena Cava	4
MULTIPLE LESIONS:	**No. of Cases**
Ascending and Descending Aorta	4
Ascending Aorta + Pulmonary Artery	2
Ascending Aorta + Inferior Vena Cava	1
Aortic Arch + Pulmonary Artery	1
Descending Aorta + Pulmonary Vein	2
Pulmonary Vein + Inferior Vena Cava	1
Ascending Aorta + Pulmonary Vein + Inferior Vena Cava	1
Ascending Aorta + Pulmonary Artery + Pulmonary Veins + Vena Cava	3

Aorta	=	38
Pulmonary Artery	=	8
Pulmonary Veins	=	10
Vena Cava	=	11
Total Lesions		67

EXCRETORY SYSTEM

In 8 individuals injuries to the kidneys (7), ureters (1), or bladder (1) occurred. Thirteen additional cases of retroperitoneal perinephric hemorrhage were noted. Kidney trauma occurred in only 4.6 per cent of impacts. Injuries consisted of 3 superficial lacerations, 3 cases of hemorrhage in the renal pelvis, one laceration and rupture, and one slight contusion.

CENTRAL NERVOUS SYSTEM

Injury to the brain was most typically subarachnoid hemorrhage, with occasional petechiae, focal ecchymotic zones, perivascular, or epidural hemorrhages present. Contusion of the lobes or lacerations occurred in several cases. As noted in the discussion of skull fractures, brain injury occurred in 62 cases (30.8 per cent); however, it is interesting to note that in half of these cases, there was no skull fracture. The spinal cord was lacerated or contused in 6 cases, in 4 of which there was also brain injury.

SKELETAL SYSTEM

Only fractures which were grossly demonstrable at autopsy were noted. As listed in Table IV, rib fractures were by far the most typical skeletal injury, with 144, or 85.2 per cent occurring.

The force of impact, particularly in transverse or lateral body orientations, caused extensive fractures to the rib cage, usually bilateral and multiple fractures involving every rib. These were of particular importance as the primary causation, through multiple invasion of the thoracic area, of penetration type lacerations to the heart, great vessels, lungs, and liver. Usually these were in both the mid-clavicular and posterior axillary line, and compound through the pleural space.

Skull fractures occurred in 40 cases, or nearly one-fourth of these impacts. In 14 cases of skull fracture, microscopic examination revealed no clinical evidence of brain trauma, thus indicating that skull fracture is not necessarily a critical measurement of irreversible CNS trauma. Conversely, 35 cases, or 56.4 per cent of brain damage occurred without skull fracture.

Vertebral fractures occurred in 25 cases, with another 20 receiving pelvic fractures or separation of the pubic symphysis. Thirteen cervical fractures occurred, 6 of which were also associated with a fractured skull. Seventeen individuals received no fractures at all, probably impacting in a head-first or feet-first ($\pm G_z$) body orientation. Fractures to the upper extremities occurred in 25 cases and in 24 cases to lower extremities.

TABLE IV. INCIDENCE OF SKELETAL FRACTURES

Gross Location	No. of Cases	
Skull	40	
Cervical Vertebra	13	25
Thoracic Vertebra	8	
Lumbar Vertebra	1	
Sacral/Coccygeal Vertebra	3	
Pelvis	20	
Ribs	144	
Upper Extremities	25	
Lower Extremities	24	
Scapula and Clavicle	18	
Total	296	

REPRODUCTIVE SYSTEM

There were no injuries in any of these cases to the reproductive system. Although one woman was pregnant and in her second trimester, there was no injury to the uterus or fetus.

DISCUSSION

Discussion of these findings would be incomplete without consideration of the factor of drowning in water impact as a cause of death or contributing factor. In 45 cases (26.6 per cent) drowning was listed as a probable or possible cause of death. In more closely evaluating these cases on a basis of concomitant trauma it is apparent that many would not have survived the impact injuries whether or not drowning was a factor. Of these, 22 individuals had trauma to the heart, great vessels or spleen, 16 had brain injuries, and 37 had lung penetrations, either singly or in combination. It is equally evident that 8 individuals who made fatal jumps from the Golden Gate Bridge died primarily from drowning and not as a result of impact trauma. Two individuals had no other injuries. In these latter cases, the individual perhaps couldn't or wouldn't swim for various reasons. Debilitation as a result of fractures to the extremities, as may occur in attempted evacuation during commercial airliner post-crash fires, may be an important factor, as well as the environmental conditions of clothing, waves, tide and exposure.

Injuries received in water impact often differ in nature and patterns from those impacts occurring on steel, soil or concrete, primarily in the lower incidence of fractures and external lesions. But two major factors play an important role in this regard, in either water or non-water impact: duration of deceleration and body orientation. Previous studies have demonstrated that a water impact in the feet-first ($+G_z$) body orientation can result in considerably less trauma than an impact in lateral or transverse positions due to the smaller surface area and thus longer deceleration involved.

A previous study of water impact survival in free-fall has demonstrated that the critical velocity (corrected for aerodynamic drag) for human survival of water impact in the feet-first body position appears to be at slightly over 100 ft/sec (30.48 m/sec), five individuals having survived impacts of 100-116 ft/sec (30.48-35.30 m/sec) impact velocity.[11] Since that time, 3 additional water impact survivals have occurred in that range.[12] However, the highest impact velocity survived in the lateral ($-G_y$) body orientation was 87 ft/sec (26.52 m/sec), 88 ft/sec (26.82 m/sec) in the prone position ($-G_x$), 93 ft/sec (28.35 m/sec) in supine ($+G_x$), and 97 ft/sec (29.52 m/sec) head-first ($-G_z$). From these water impact survival data, since the fatal cases reported in this study impacted at from 108-110 ft/sec (32.92-33.53 m/sec) (corrected) and considering the nature and site of the majority of the trauma (such as high incidence [85.2 per cent] of penetrating rib fractures), it is believed that most of these fatal impacts, excluding the eight who died primarily from drowning, impacted in transverse or lateral combinations of body orientation. This is further supported by the previous experimental water impacts with anesthetized guinea pigs, in an attempt to reproduce trauma in freefall of the two 1954 Comet airline ruptures which spilled their occupants into the sea.[1] Stunt divers at Acapulco, Mexico, routinely dive up to 135 feet (86 ft/sec, or 26.2 m/sec) in the $-G_z$ orientation.[9]

Tests conducted with an instrumented anthropometric dummy in various body orientations produced measured G forces exceeding 500 G's at only 9.14 m/sec impact velocities, less than one-quarter the impact velocity of these fatal cases.[5] Both the nature of the trauma and these experimental tests suggest that for pure water impact, considerably greater protection of the thoracic cage will be required for human survival of high velocity $\pm G_{x,y}$ impacts.

CONCLUSIONS

The necropsy reports and environmental data were studied for 169 individuals (52 female and 117 male) who had received fatal trauma in freefall water impacts. All were incurred in jumps of 239 to 261 feet, or 108-110 ft/sec (32.92-33.53 m/sec) impact velocities, from the Golden Gate Bridge in San Francisco, thus constant environmental factors of velocity, a water impact surface, and autopsy results were available for each. To date, of 305 jumps from this bridge, there have only been 2 survivors. This study is intended to complement earlier work concerning survival tolerances in water impact by providing data on mechanisms and causations of fatal injuries.

SUMMARY

The most common mechanism of injury was crushing of the thoracic cage with resultant multiple bilateral fractures of the ribs which penetrated the vital organs. Fractured ribs occurred in 85.2 per cent of these fatal impacts.

In 76 per cent of these cases, the lungs were lacerated, usually by intrusion of rib fragments.

The liver was ruptured in 53.8 per cent of these impacts.

Cardiovascular trauma ranged from contusive blunt impact-type injuries to frank disruption of a major vessel or chamber. Only 5 of the 87 were not associated with multiple fractures, the bony thorax penetrating the pericardial or pleural cavities. Forty-two cases occurred in which one or more chambers of the heart were ruptured, with the left atrium most vulnerable. Traumatic rupture or laceration of one or more of the great vessels was found in 45 cases, with aortic ruptures most frequent. The twelve cases of cardiac and great vessel rupture occurred together.

Brain injury, most commonly in the form of subarachnoid hemorrhages, occurred in 62 cases, in half of which skull fracture did not occur.

Kidneys were not found to be as vulnerable to injury as generally believed, only 8 (or 4.6 per cent) receiving contusions, laceration or rupture. Retroperitoneal perinephric hemorrhage was found in 13 cases.

Skull fractures occurred in 40 cases, or in nearly one-fourth of these impacts. However, in 14 of these cases histological examination revealed no brain trauma.

Seventeen individuals received no fractures at all, and in 45 cases (26.6) drowning was a probable or possible cause of death. It is believed that in eight cases, impact trauma was not sufficient to be fatal and that three individuals drowned post-impact. These individuals appeared to have impacted in the foot to head ($+G_z$) orientation.

These data reinforce previous survival information indicating that the extreme limit of human impact water survival ranges close to 116 ft/sec (35.30 m/sec), but that body position at impact is critical. For non-fatal transverse and lateral impact ($\pm G_{y,x}$) in pure water environments additional protective restraint must be considered.

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