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The Medical Investigation of Airship Accidents

REFERENCE: Stahl, C. J., McMeekin, R. R., Ruehle, C. J., and Canik, J. J., **"The Medical Investigation of Airship Accidents,"** *Journal of Forensic Sciences,* JFSCA, Vol. 33, No. 4, July 1988, pp. 888–898.

ABSTRACT: A review of the autopsy reports for 18 of 21 victims in 3 of the 4 nonrigid Navy airship accidents during the period 1955 to 1966 revealed that the patterns of injury, complicated by postcrash entrapment, immersion, or fire, are similar to the injuries observed in the low-speed, low-altitude crashes of rigid airships and of light aircraft. With the renewed interest in the development of airships for military purposes, there is a need for improved design related to crashworthiness and to aircrew habitability, safety, restraint, and egress in order to enhance the chance for survival in the event of an accident.

KEYWORDS: pathology and biology, aircraft, accidents, aircraft accidents, airship accidents, human factors, medical investigation

The medical investigation of aircraft accidents during the past 30 years has contributed not only to improvements in aviation safety and aircraft design, but also to a better understanding of the human factors related to these accidents. Commercial, general aviation, military, rotary wing, parachute, and ultralight accidents have been evaluated, and the results of these medical investigations, excluding airships, have been discussed in articles and textbooks [*1–15*].

During the decades before World War II, the long-range endurance and the economical operation of rigid airships—or dirigibles—for commercial travel, military surveillance, and aerial deployment of fighter aircraft were recognized in the United States and abroad. The high cost of helium, the flammability of hydrogen, and the lack of adequate instruments for navigation, communication, and weather, as well as the high potential for loss of costly resources and lives in the event of a disaster, were impediments to the successful development of safe rigid airships. The ill-fated flights of the rigid U.S. Navy airship, *Shenandoah,* in 1925 [*16*], and the German dirigible, *Hindenberg,* a decade later, ended this phase of aviation.

The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the Department of the Army, the Department of the Air Force, or the Department of Defense. Received for publication 27 Aug. 1987; revised manuscript received 19 Sept. 1987; accepted for publication 22 Sept. 1987.

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Smaller nonrigid airships, inflated with helium, were used by the Navy for surveillance and escort of ships in convoy during World War II, as well as for coastal and antisubmarine surveillance until 1962 [*17*]. Airship Wing One, Squadrons ZP-1 and ZP-3, were decommissioned at Naval Air Station, Lakehurst, New Jersey, on 31 Oct. 1961. Two patrol airships were maintained for research and development duties until the last flight of a Navy airship on 31 Aug. 1962 [*18*].

There is renewed interest in the use of airships not only for fleet escort, antisubmarine warfare, and missile launch detection, but also for search and rescue, narcotics interdiction, and transport of personnel to remote stations. During fiscal year 1984, the Navy received $5 million for development of a prototype airship [*17*]. While the operational advantages of airships are apparent, their vulnerability to attack [*19,20*] and to adverse weather conditions, as well as the safety of crew members, will need to be considered. This report discusses four historic airship accidents. The medical aspects of these accidents, including human factors, preexisting diseases, and patterns of injuries, may provide guidance for improved design related to safety, habitability, restraints, and egress.

Patrol Airships

During the years 1951 to 1962, nonrigid patrol airships included models ZPG-2 (Fig. 1), ZPG-2W (Fig. 2), ZPG-3W (Fig. 3), and ZS2G-1, valued at $3.9, $3.5, $10.0, and $2.3 million, respectively [*21,22*]. The ZPG-2 models, deflated for storage, measured 76 ft (23 m) in width, 97 ft (29.5 m) in height, and 343 ft (104.5 m) in length. Early warning airships were models ZPG-2W and ZPG-3W. The ZPG-2W had engines mounted inside the gondola, carried a crew of 21 officers and enlisted personnel, and measured 107 ft (33 m) in height. The larger, more costly ZPG-3W measured 85 ft (26 m) in width, 118 ft (40 m) in height, and 404 ft (123 m) in length and had an internal antenna measuring 42 ft (13 m) [*18*].

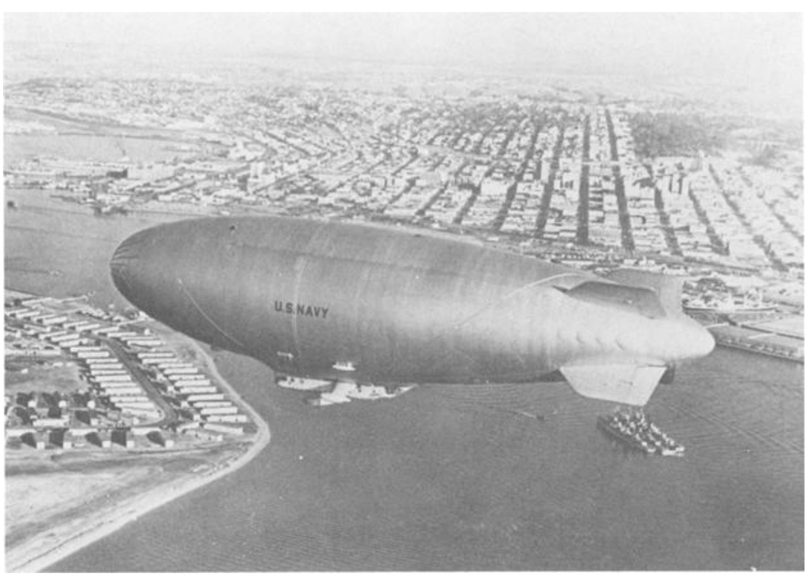

FIG. 1—*Airship Model ZPG-2. (From the Ship and Aircraft Photograph Collection, U.S. Naval Institute.)*

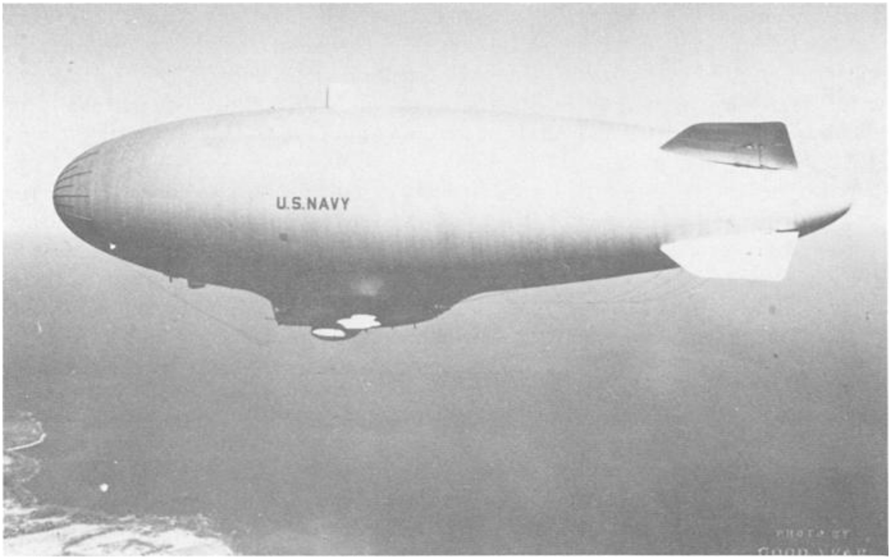

FIG. 2—*Airship Model ZPG-2W. (From the Ship and Aircraft Photograph Collection, U.S. Naval Institute.)*

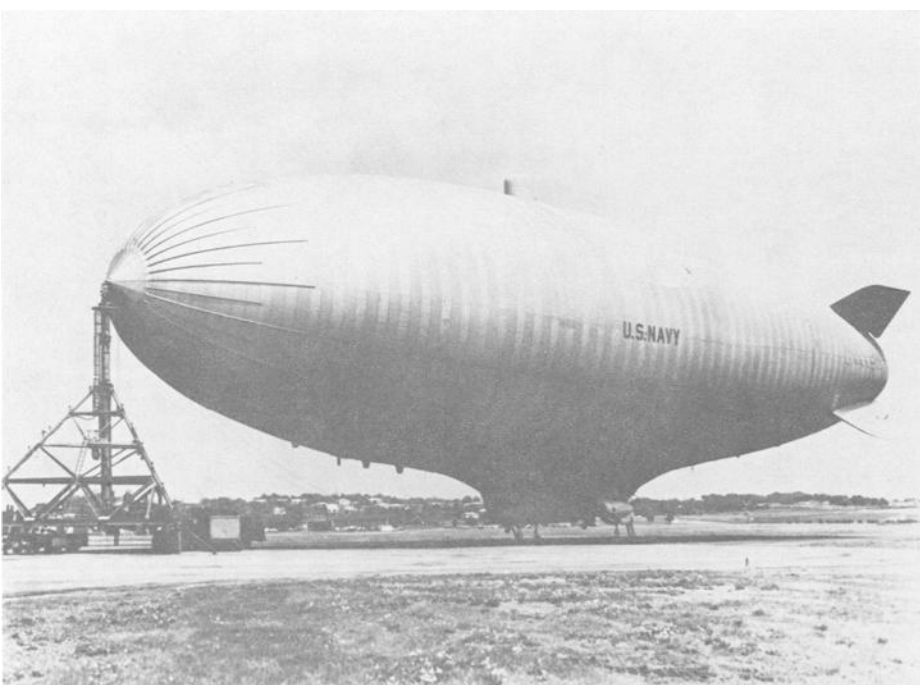

FIG. 3—*Airship Model ZPG-3W. (From the Ship and Aircraft Photograph Collection, U.S. Naval Institute.)*

Materials and Methods

Review of the records at Naval Safety Center, Norfolk, Virginia, disclosed reports of 4 fatal nonrigid airship accidents during the period of 1955 to 1962 (Table 1). A search of the files at the Armed Forces Institute of Pathology for the same period revealed autopsy reports for 16 of the 21 fatalities in the ZPG-2, ZPG-3W, and ZS2G-1 accidents. Two additional autopsy reports from the ZS2G-1 accident were obtained from the Laboratory Service, Naval Hospital, Camp Lejeune, North Carolina. No records, including the autopsy report, were available for the ZPG-2W accident victim. An autopsy report was available for only one of the three fatalities in the ZPG-2 accident.

Report of Cases

ZPG-2 Accident

While landing at Naval Air Station, Lakehurst, New Jersey, at 0130, 14 May 1959, the airship struck Hanger No. 3 at an unknown speed, an altitude between 40 and 80 ft (12 and 24 m), and an impact angle of 45°. The accident occurred in darkness, fog, and rain at an air temperature of 50°F (10°C). There was no movement of the airship after the impact. There were three fatalities, but information concerning two persons is not available. The body of an officer, who had been seated topside at the rear of a table, was found in the wreckage of the gondola with his back against the bulkhead. The table and a 300-lb (136-kg) ice box compressed his abdomen, and the table and a seat cushion compressed his face and trunk.

Postmortem examination the same day revealed abrasions and contusions of skin; petechiae of scalp, skin, buccal mucosa, conjunctivae, trachea, bronchi, thymus, pleural surfaces, epicardium, and endocardium; contusion of the thoracic spinal cord; and bilateral, nondisplaced fractures of ribs. There were no significant preexisting diseases, and neither ethanol nor carbon monoxide were found by toxicologic examination of urine and blood, respectively. The death was attributed to asphyxiation by crush injury of the chest and abdomen.

ZS2G-1 Accident

Two airships, model ZS2G-1, departed from Glynco Naval Air Station, Brunswick, Georgia, at approximately 1850, on 16 Feb. 1959, for a ferry flight to Naval Air Station, Lakehurst, New Jersey. Before the flight, one engine of the lead airship did not develop full power and caused a delay in takeoff. The lead airship had a crew of seven personnel, including the commander, pilot, copilot, first and second radiomen, mechanic, and rigger. It weighed 5391 lb (2445 kg) and carried 8000 lb (3630 kg) of fuel and 2600 lb (1180 kg) of water. The flight plan called for visual flight rules at an altitude of 600 ft (183 m). North of Savannah, Georgia, the lead airship reported malfunction of the navigation radios and requested the other airship to take the lead. The following airship maintained visual and VHF radio con-

TABLE 1—*Nonrigid airship accidents, 1955–1962.*

Date	Model	Location	Fatalities	Phase of Flight
14 Nov. 1957	ZPG-2W	Lakehurst, NJ	1	unknown
14 May 1959	ZPG-2	Lakehurst, NJ	3	landing
17 Nov. 1959	ZS2G-1	Pinetown, NC	4	in-flight
6 July 1960	ZPG-3W	Atlantic Ocean	13	in-flight

tact 1 to 2 miles (1.6 to 3.2 km) astern of the new leader, but also reported malfunctions of the autopilot altitude control and the radio altimeter. Manual controls were used to maintain an estimated altitude of 600 to 650 ft (183 to 198 m).

The airship had a poor design for safety of aircrew personnel. Two bunks required a head-forward position of occupants and were located adjacent to the engines, exposing the occupants to constant noise. The only controls were located near the pilot seat in the cockpit, and there were no alternative controls at the functionless copilot's seat. Shoulder restraints were not available on cockpit seats. The use of lap belts was not mandatory. Lap belts on cockpit seats were not utilized by the crew. Windows in the cockpit were not designed for emergency egress. There were no air jets for ventilation at the pilot's seat, and the cargo door was the only escape route. Personnel were not equipped with fire-retardant flight suits and gloves.

At 2300, on 16 Feb., the pilot relieved the copilot at the controls. At midnight, the crew had a full steak meal. The copilot went to sleep on the forward starboard bomb bay tank. The first radioman and the mechanic occupied the bunks. The rigger sat in the copilot's seat and attempted to maintain visual contact with the lead airship while the second radioman was at the radio. The commander manned the radar and navigation equipment. The lead airship was unable to contact the following airship on UHF radio channels.

Using manual controls, the pilot observed a recorded altitude of approximately 600 to 700 ft (180 to 210 m) but believed the altitude was approximately 1100 ft (335 m). The airship maintained a speed of approximately 45 to 55 knots (23 to 28 m/s). The air temperature was 46°F (7.7°C) and there were southerly winds of 2 to 5 knots (1 to 2.5 m/s), high clouds, haze, and visibility of 6 to 10 miles (10 to 16 km).

At 0145, on 17 Feb., the copilot looked out a forward window and saw trees. Without warning, the airship struck 120-ft (36.5-m) pine trees in Dismal Swamp, located 2 miles (3 km) west of Pinetown, North Carolina, and 18 miles (29 km) north of Washington, North Carolina. After the initial impact, the crew noted the odor of gasoline fumes. The airship burst into flames and crashed 300 yd (274 m) from the site of initial impact. Witnesses at Pinetown heard explosions and observed the fire in Dismal Swamp at 0150, and they initiated the rescue of three survivors who had sustained severe burns and fractures and were in shock. Pine trees penetrated the cockpit of the airship and ripped off the cargo doors. The copilot, seated in a jump seat facing aft at the time of the crash, escaped through a broken forward window in the cockpit. Another survivor escaped through the cargo hatch.

The bodies of the four fatalities in the airship accident were recovered from the center of the wreckage. They were identified by dental records and identification tags, and they had sustained severe 100% total body-surface-area burns. Toxicologic examinations of two of the four victims were negative for ethanol. Specimens for determination of carbon monoxide, submitted in only one case, revealed 17% saturation. Postmortem examinations did not provide evidence of any preexisting diseases.

The total destruction of the airship resulted in the loss of four lives, severe injuries to three survivors, and over $2 million in damage. Airframe failure, environmental conditions, and preexisting diseases did not contribute to the crash. The design of the airship did not provide alternate controls for the copilot and alternate means for egress. Shoulder restraints and lap belts were not installed on all seats, and their use was not mandatory. Fire-retardant flight suits and gloves were not issued to crewmen. There were no low-altitude warning devices. The location and position of bunks did not allow for safety in the event of turbulence or impact. The in-flight failures of the autopilot altitude control and radio altimeter were not compensated in a satisfactory manner by manual control.

ZPG-3W Accident

The airship assigned to Airship Airborne Early Warning Squadron One, Naval Air Station, Lakehurst, New Jersey, was on patrol over the Atlantic Ocean approximately 16 miles

(26 km) southeast of Barnegat Light. The airship had 21 officers and crew, and it was flying at an altitude of 300 ft (90 m) in weather conditions of broken clouds, winds of 13 knots (7 m/s) visibility of 12 miles (19 km), and temperature 71°F (22°C). Without warning, the airship deflated spontaneously at 1425, on 6 July 1960, crashed into the ocean within 5 s and submerged to a depth of 55 ft (17 m). The air-to-water crash occurred at latitude 39-44.3 N and longitude 73-46.1 W, approximately 8 miles (13 km) southeast of Barnegat Light. There were eight survivors and thirteen fatalities (Tables 2, 3). Twelve of the victims died as the result of entrapment in the wreckage and drowning (Table 4). Divers recovered their bodies two to six days after the accident. One fatal victim was rescued from the ocean on the day of the accident. He sustained severe decelerative injuries, including fractures of the pelvis, and he showed clinical signs of paraplegia. He died enroute to shore.

Discussion

After Count Ferdinand von Zeppelin built the first rigid airship at the end of the last century, Germany and other nations recognized the advantages of airships for long-range surveillance, commercial transportation, and warfare. During World War I, Germany had twenty zeppelins in operation by 1917 [*23*]. In 1919, the Federal Government purchased 1700 acres (6880 km^2) of land in New Jersey for a dirigible field, and the command, Naval Air Station, Lakehurst, was established by 1921 [*23*]. The era of the rigid naval airship lasted less than two decades [*23*]. Four of the five rigid airships had crashed by 1935 (Table 5), and their high cost, low speed, vulnerability to adverse weather conditions, and loss of significant numbers of lives in peacetime resulted in the funding of less costly and improved airplanes.

The investigations of rigid airship accidents focused on their structural design and the effects of environmental conditions, without significant attention to human factors. Nevertheless, recommendations were made to improve the survivability of aircrew members. After the breakup and crash of the *Shenandoah* in a storm over Ohio, the board of inquiry for the disaster of the *Akron*, which was lost at sea in a storm off Barnegat Light, New Jersey, noted that the absence of life-saving equipment and the cold water contributed to the 73 deaths [*23*]. The crash of the *Macon*, 2 years later, off Point Sur, California, resulted in the deaths of only 2 of 83 crewmen who had life preservers and rafts [*23*]. The investigations of the crashes of the *Akron* and *Macon* indicated the need for greater attention to human factors. Each airship cost $4 million. When the *Akron* crashed into the sea during a storm, it was flying at an altitude considerably lower than the altitude perceived by the crew. At that time, altimeters were modified aneroid barometers. For each decrement of 0.1 in. (0.25 cm) of mercury in barometric pressure during a storm, the altimeter required compensation by change in altitude of 100 ft (30.5 m). It is believed that the *Akron* flew into the eye of the storm and that the crew did not change the altimeter settings to compensate for the rapid changes in barometric pressure [*24*]. The Durand Committee, appointed to investigate the crash of the *Macon*, recognized not only the effects of adverse weather conditions on the airship, but also noted there was a poor system for communications and no system for a general alarm. Hurried actions by crewmen to correct uncertain flight conditions to restore the ship's trim contributed to the accident [*24*].

Many of the experiences gained from the investigation of rigid airship accidents were not utilized to improve aircrew safety in the nonrigid airships. The multidisciplinary problems associated with the investigation of aircraft accidents became apparent in 1954, after the *Comet* disasters—the British commercial jet aircraft. The Joint Committee on Aviation Pathology and the Aerospace Pathology Branch, Armed Forces Institute of Pathology, were established in 1955 and 1956, respectively, to organize the study and the evaluation of human factors in aircraft accidents. The three categories for study included environmental factors, traumatic factors, and preexisting disease [*25*]. The guidelines for the investigation and evaluation of military aircraft accidents by multidisciplinary teams became available

TABLE 2—*Traumatic injuries of 13 fatalities. ZPG-3W accident, 6 July 1960.*

	Fractures										Lacerations				
No.	Skull	Mandible	Sternum	Clavicle	Scapula	Ribs	Vertebrae	Pelvis	Tibia	Fibula	Pericardium	Lung	Spleen	Liver	Kidney
1								X							
2			X	X		X	X				X		X		X
3	X				X	X	X						X	X	X
4	X					X							X		
5	X	X				X	X		X			X	X	X	
6		X				X	X	X				X	X	X	
7	X	X				X	X			X					
8					X	X		X		X					
9															
10															
11						X	X				X	X		X	
12															
13						X							X	X	

TABLE 3—*Coronary artery disease in 13 fatalities, ZPG-3W accident, 6 July 1960.*

Grade	Number	Percent
0[a]	9	70
1[b]	2	15
2[c]	2	15

[a]0-None.
[b]1 = Less than 50% occlusion.
[c]2 = 50% or more occlusion.

TABLE 4—*Chemical and toxicologic examinations of 13 casualties, ZPG-3W accident, 6 July 1960.*

No.	Alcohol	Carbon Monoxide, %	Chloride, mEq/L	
			Right Heart	Left Heart
1	...[a]	10	[b]	[b]
2	...	10	100	[c]
3	...	10	46	165
4	...	10	125	165
5	...	10	[b]	[b]
6	...	10	[b]	[b]
7	...	10	109	135
8	...	10	98	180
9	...	10	150	165
10	...	10	95	122
11	...	10	76	94
12	...	10	108	131
13	...	10	153	200

[a]None found.
[b]Not performed.
[c]Insufficient specimen.

TABLE 5—*Rigid naval airships, 1921 to 1940.*[a]

Number	Name	Commis-sioned	Last Flight	Outcome	Fatalities	Survivors
ZR1	*Shenandoah*	1923	9/3/25	crashed	14	29
ZR2	*British R-38*	...	8/24/21	crashed	44	5
ZR3	*Los Angeles*	1924	6/25/32	scrapped (1940)	...	...
ZRS4	*Akron*	1931	4/4/33	crashed	73	3
ZRS5	*Macon*	1933	2/12/35	crashed	2	81

[a]Adapted from Ref *23*.

near the end of the era of the airship and directed attention initially to fixed-wing aircraft [*26,27*].

The jurisdictional problems in the on-the-scene investigation of commercial aircraft accidents and the authorization of postmortem examinations for victims have been resolved to a great extent by the Federal Aviation Act of 1958, as amended in 1962 [*28*]. Each of the military services has directives for the investigation of military aircraft accidents, and the jurisdictional relationships among the National Transportation Safety Board, the military services, and the state offices for medicolegal investigations are discussed by Lilienstern [*29*]. During the period 1955 to 1962, joint regulations and Navy directives provided the guidance for Naval investigations of aircraft accidents [*21,22,30*]. The investigation of aircraft accidents has several purposes: (1) to determine the identity and the cause of death of victims; (2) to evaluate the relationship between preexisting diseases and the cause of the accident; (3) to determine the relationship between the pattern of injuries and the design of the aircraft and equipment; (4) to determine environmental and weather conditions related to the flight and the accident; (5) to determine causes for airframe and power failures; (6) to determine factors contributing to escape, rescue, and survival as well as factors related to design, equipment, and instrumentation that could improve the chance of survival and reduce the severity of injury; and (7) ultimately to determine the primary cause of the accident [*13,14,29*].

The accidents of the nonrigid airships occurred at low speeds and low altitudes, either at night or in adverse weather conditions, and without adequate personnel and equipment restraints, safety and survival gear, and methods for egress. Rupture of fuel tanks and lines upon impact as well as in-flight malfunctions of the altimeter, the autopilot, and the communications instruments played a role in the ZS2G-1 accident. These accidents are similar not only to the disasters involving the large rigid airships decades earlier, but also to the low-speed fatal accidents of light fixed-wing aircraft, rotary wing aircraft, and gliders. The characteristics of these accidents include not only injuries from deceleration, flailing, and structural deformation of the aircraft, but also the potential for entrapment, drowning, and burns from postcrash fires [*14*]. Nonrigid airship accidents had a greater potential for conflagration upon impact, because crashworthy fuel tanks were not developed until a decade after the decommissioning of these airships. The large size, complicated structure, and interior compartments of airships also contributed to slow egress and the chance for entrapment.

Structural failure of airframes during severe storms and turbulence contributed to disasters of rigid airships when winds exceeded design gust limits. Clear-air turbulence, as well as extreme vertical wind velocities in storms, may result in loss of control, overreaction attempts at control, or unexpected and rapid changes in altitude. The *Shenandoah* and *Macon* disasters resulted from structural failures in storms. There are no similar incidents among the nonrigid airships in this series, but the sudden deflation and crash of ZPG-3W into the sea is considered to be in this category. Snyder [*31*] reviewed in-flight structural failures involving general aviation aircraft and cited a National Aeronautics and Space Administration study of 67 ft/s (20 m/s) updraft velocities in thunderstorms, with computed velocities of 160 ft/s (49 m/s). Violent up-and-down drafts, exceeding 3000 ft/s (914 m/s), may occur with moist, warm unstable air and an uplift action from terrain wind turbulence of increased ambient temperature. He also noted that the human tolerance to vertical impact is 25 *g* for 100 ms at 250 to 300 *g* per second rate of onset, while injuries will occur at 95 *g* for 7.5 ms.

The distribution of fractures and lacerations in light aircraft accidents among three series compiled by Reals [*13*] is similar to the distribution of injuries among victims of the ZPG-3W accident (Table 2). In all aircraft accidents, radiographic examinations of bones in all fatalities are indicated not only to determine the extent of injuries and to contribute to the identification of victims, but also to evaluate the magnitude, direction, and rate of mechanical forces that caused the bony injuries [*32*]. Some of the victims of nonrigid airship accidents may have survived their traumatic injuries when the crash forces were within the limits of human tolerance and the structure of the aircrew spaces remained intact. In their study of Army aircraft accidents during the five-year period fiscal year 1965 through fiscal year 1969, Berner and Sand [*33*] found that 93.5% of all accidents were survivable and that 39.4% of all fatalities resulted from accidents classified as survivable by the Army. Entrapment in fire and water, resulting in burns and drowning, respectively, as well as significant traumatic injuries, contributed to the deaths in survivable accidents.

Conclusion

In summary, review of the circumstances in 3 of the 4 nonrigid airship accidents for the period 1955 to 1962 and of the postmortem findings in 18 of the 21 victims indicates that these accidents occurred at low speeds and altitudes, with deaths resulting from flailing, decelerative, and crush injuries as well as from postcrash drowning and burns. Two of the accidents occurred at night, and malfunction of instruments contributed to one of these crashes. Except for the sudden deflation of one airship, there were no airframe failures. There was no evidence of significant preexisting diseases or alcohol in the victims. The patterns of injury are similar to those observed in the victims of low-speed crashes of light aircraft and rigid airships complicated by postcrash entrapment, fire, and immersion in water. The chances for survival in these accidents would have been greater with more reliable communication and navigation instruments, restraints for personnel and equipment, fire-retardant clothing, and alternative means for egress.

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