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Investigation of Hot Air Balloon Fatalities

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ABSTRACT: The rising popularity of the sport of hot air ballooning has been accompanied by several recent incidents, both in this country and other parts of the world, where mechanical defects and the improper operation of balloons have resulted in several fatalities. A study was conducted to identify the location and frequency of hot air ballooning accidents. Furthermore, the study attempted to identify those accidents that were the result of improper handling on the part of the balloon operators and those that were related to specific defects in the construction of the balloon. This paper presents a background of the sport of hot air ballooning, together with an analysis of the construction of a typical hot air balloon, pointing out the specific areas where defects may occur that could result in a potential fatal balloon crash. Specific attention is given to the two recent balloon crashes that occurred in Albuquerque, NM, hot air balloon capital of the world, and that resulted in multiple fatalities.

KEYWORDS: forensic science, balloons, deaths

Hot air ballooning is a rapidly growing recreational, sporting, and promotional activity. It is estimated by Patricia Barz, President of the Balloon Federation of America, that there are 6000 hot air balloons and 5300 pilots and student pilots in the United States.[4] According to Sid Cutter, President of the World Balloon Corp., these numbers have increased from approximately 50 balloons and 100 pilots in 1972.[5] The hot air balloon was invented and first successfully flown in 1783 in France by the brothers Joseph and Etienne Montgolfier [*1*]. A gas (hydrogen) balloon was constructed and flown later the same year by J. A. C. Charles [*1*]. Because a free balloon, hot air or gas, is classified as an aircraft, it must be registered and certified airworthy by the Federal Aviation Administration (FAA). The balloon pilot is also under the same aegis for the receipt or purveyance of certified ground and flight instruction, certification, licensing, and review.

Since the early 1970s, Albuquerque, NM, has had a wide exposure to hot air ballooning, because of its consistent weather patterns, open spaces, cooperative landowners, and several large and well-organized balloon rallies which have since evolved into a yearly international ballooning event. As a result, Albuquerque has had the most balloons in the air at one time

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[4]Patricia Barz, president, Balloon Federation of America, personal communication, April 1984.

[5]Sid Cutter, president, World Balloon Corp., personal communication, April 1984.

and the most consecutive days flown, with usually good safety records. However, this concentrated ballooning activity has also increased the potential dangers inherent in this sport.

It is the purpose of this article to outline the anatomy and physiology of hot air ballooning, to describe two fatal accidents which occurred in Albuquerque, and to discuss those lessons in safety learned from our investigation.

Anatomy of a Hot Air Balloon

As noted in Fig. 1, the envelope, the lifting portion of the aircraft, is divided into sections: the crown or top, the body made up of vertical gores, the throat and the cables, and cable blocks. The crown line and ground handling lines are utilized while the balloon is on or very close to the ground. The top or deflation port is opened by a cable or line or both attached to the gondola. Similarly, in those balloons where a maneuvering vent is present, a line is attached from the vent to the gondola. The envelope fabric is ordinarily light-weight rip-stop nylon, and load tapes, where utilized, are 25.4- to 50.8-mm (1- to 2-in.) nylon tapes of various thicknesses. The seams and sewing must conform to the manufacturers' FAA approved design. The skirt, which may be constructed of nylon or burn-resistant material, is not considered part of the airframe and is used only for burner flame/wind control when the balloon is not moving with the mass of air (tethered, on the ground, or in wind shears). A commonly configured envelope may contain 1415 to 2831 m^3 (50 000 to 100 000 ft^3) of air inflated and weigh 68 to 113 kg (150 to 250 lbs).

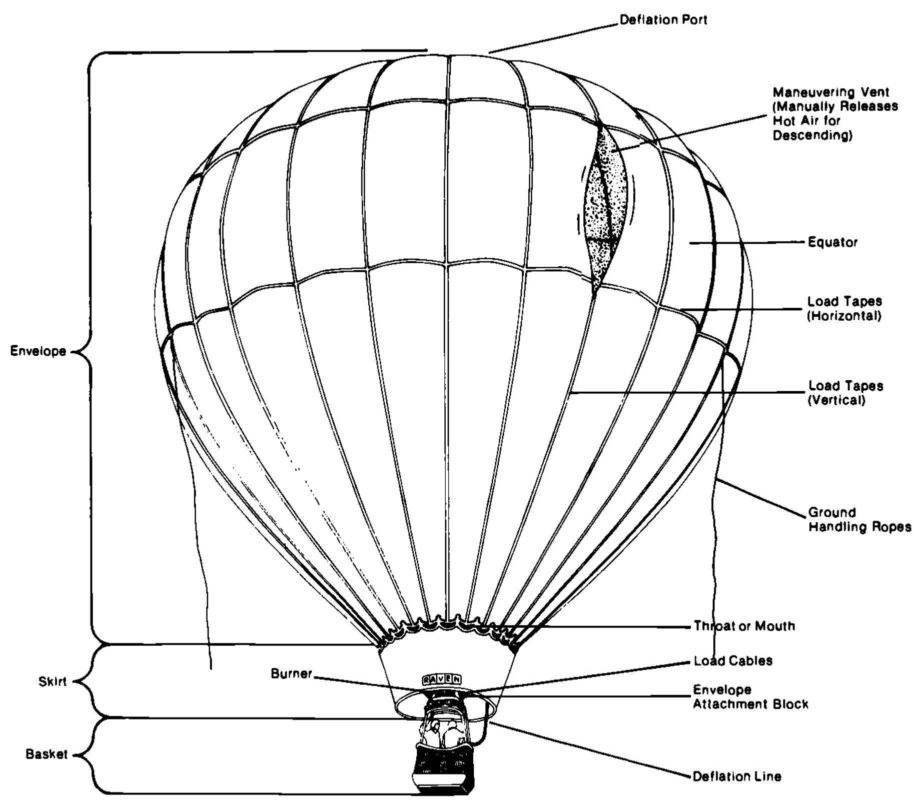

FIG. 1—*Diagram of hot air balloon envelope (Courtesy of Raven Industries, Inc.).*

Figure 2 shows an example of a wicker and aluminum gondola, including burners (one to four), hoses, propane tanks, and instruments. The envelope cables are attached to a rigid, upright structure which also holds the burners to the basket. With tanks full, the gondola may weigh 136 to 181 kg (300 to 400 lbs).

Adjacent to the burner is the propane vapor or liquid pilot light, which remains burning throughout the flight. Valves, cables, bolts, pins, and so forth, are all proven reliable components that meet manufacturers' specifications. Helmets, gloves, flint and steel or capacitance ignition "stryckers," tools, ropes, and nonflammable clothing are also important adjuncts to ballooning.

Physiology of a Hot Air Balloon

The balloon parts are unloaded from the "chase truck" or trailer (the more precise Europeans call this the "retrieve vehicle"), and the various pieces are assembled. The rigid upright superstructure is attached to the gondola (some gondolas do not have uprights); the burner system and cables are bolted at the envelope attachment blocks (Fig. 3). Most modern burner systems are partially or completely redundant; that is, one burner is capable of firing independently of the other. Burners are rated from 0.6 to 7.3 million W (2 to 25 million Btu/h). Ropes, cables, tapes, wires, and instruments are then assembled.

The envelope is pulled gently out of its "stuff bag" and the deflation port is checked. At least four people are required to inflate the balloon satisfactorily. Cold air is introduced via the envelope throat from an electric or gasoline powered inflator fan. When the envelope is filled to capacity with cold air, the burners are ignited (after checking all propane connections and valves by the "sniff" test). One burner set is used to heat the cold air sufficiently for

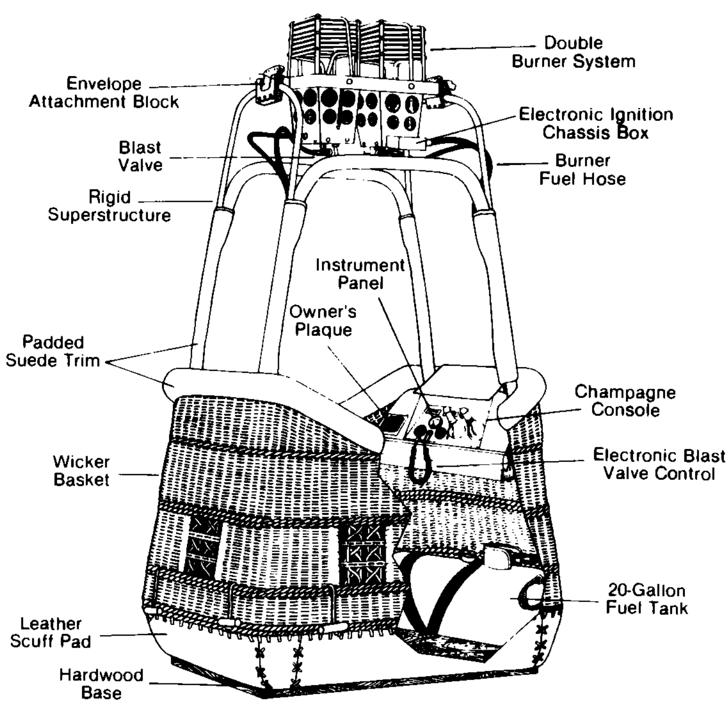

FIG. 2—*Diagram of hot air balloon gondola, including propane fuel system (Courtesy of Raven Industries, Inc.).*

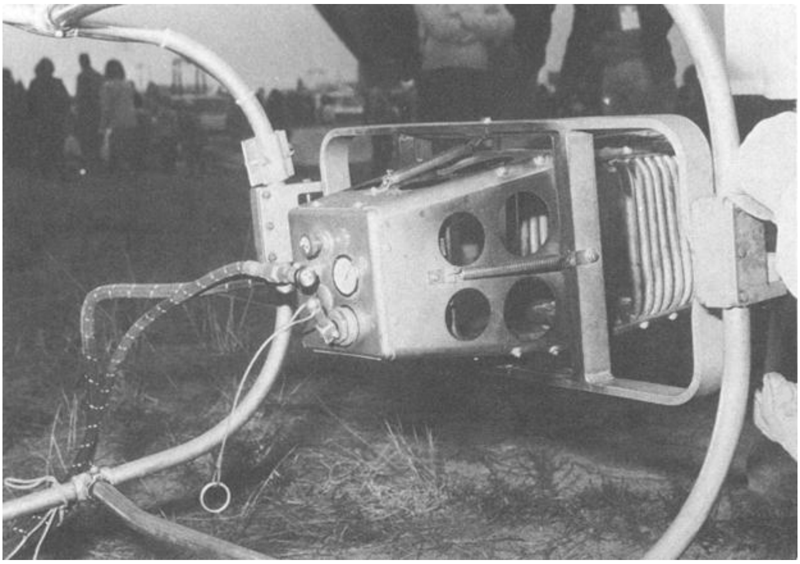

FIG. 3—*Typical burner system showing cable block attachment (photo by University of New Mexico Medical Illustrations).*

envelope buoyancy, and caution is used to avoid scorching fabric, cables, or people (Fig. 4). As the envelope begins to inflate, people holding the crown line allow the envelope to rise slowly. After the balloon is fully erect, the pilot once again checks all fittings, attachments, fabric, and other equipment. The pilot logs assembly and Velcro® closure before lift off (Fig. 5).

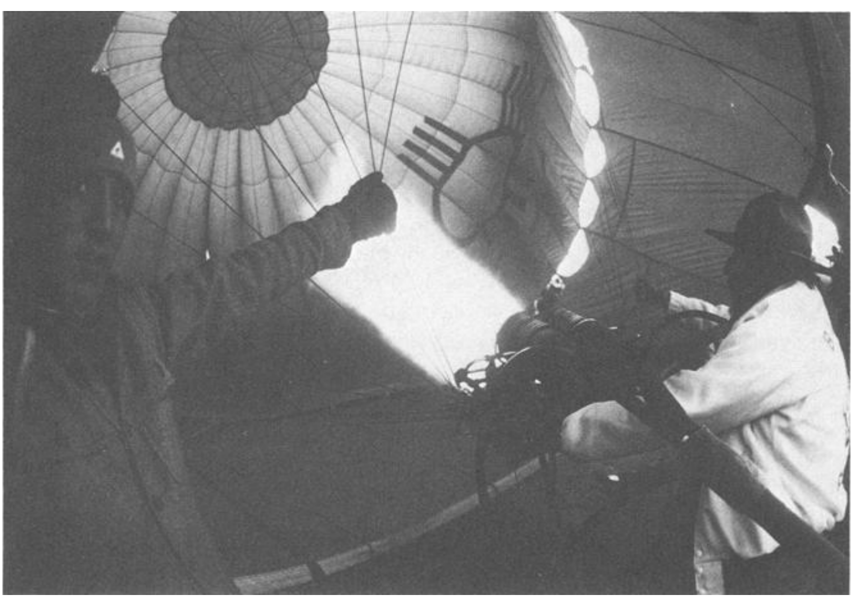

FIG. 4—*Hot air inflation of 2209 m^3 (78 000 ft^3) balloon (courtesy of Grafton M. Smith).*

FIG. 5—*Hot air balloons in various stages of flight, Albuquerque International Balloon Fiesta, October 1983 (photo by Dr. McConnell).*

Buoyancy of the hot air balloon is governed by a law of physics, a combination of Boyle's and Charles' gas laws and Avogadro's principle, called the "Equation of State" [*2*]. Simply put, lift is achieved by heating the molecules of air within a vessel whose volume and pressure remain constant; the more widely spaced the molecules, the less dense the hot air. Less dense air is lighter than the air surrounding the balloon, thus creating the lift, which is in the range of 96 to 240 kg/1000 m^3 (6 to 15 lbs/1000 ft^3) of displacement, depending on the volume of the balloon, internal temperature, ambient air temperature, and altitude above sea level at the lift-off point.

A common problem at lift-off is "false lift" [*3*]. This phenomenon occurs in combination with several factors, some of which vitiate toward negative buoyancy and some, positive.

Negative factors include gross weight, reduced balloon envelope volume secondary to windward flattening of the envelope by increasing wind pressure, and cooling of the internal hot air secondary to cooler wind passing over the fabric externally. Positive factors are "normal" lift secondary to heating the internal air by burner use and "false" lift which occurs when surface winds exceed 9.65 to 16.1 km/h (6 to 10 mph). This latter phenomenon is caused by air turbulence created by deviation of air currents from their original path by the stationary envelope and a concomitant aerodynamic conversion of velocity and static pressures which develop a mini low pressure area above and leeward of the envelope plus a mini high pressure area below the equator and windward.

False lift rapidly diminishes after lift-off as a function of acceleration to wind speed. When the balloon achieves wind speed this force is zero. The pilot must compensate for false lift effect by estimating the actual buoyancy force required under static conditions.[6]

Wind shear (a horizontally layered difference in direction or velocity or both of two air masses) may be encountered if the direction or velocity differences are great. Clear-air turbulence may be encountered in several conditions, in particular a wave or rotor (air moving over

[6]Robert Ruppenthal, president, Universal Dynamics, personal communication, Feb. 1984.

or around large obstacles, such as mountains, hills, large trees, or buildings) or with frontal or other meteorologic activity above the ground, creating different currents.

A balloon can be maneuvered only vertically (by heating more or less air, or venting hot air, or lightening the gross weight); the only movements horizontally are in air masses. Landing is accomplished by cooling the balloon (or venting hot air), thereby decreasing positive buoyancy. In light wind conditions, landings are made "standing up" and are usually gentle (final descent at less than 15 m/min [50 ft/min]). High wind landings are made by setting up a glide slope and path, shutting off and depressurizing all propane burners, pilot lights, and hoses, and massively venting hot air through the top or deflation port. This last maneuver is often called "ripping" or "ripping out" or "popping the top" (Velcro, when used, makes a ripping sound as the hooks come out of the pile) (Fig. 6). Air is completely vented from the envelope, and the fabric is then "squeezed" or "stripped" to remove all of the air from the envelope. The envelope is stuffed into its storage bag and the cables (and sometimes burners) are disassembled. Most balloonists store their equipment in their home garage or an outbuilding. (Propane tanks are not stored in the house or a connected garage.)

Case Reports

Case 1

In October 1979, during the annual International Balloon Fiesta in Albuquerque, a group of balloonists decided to fly in the late afternoon. They chose as their take-off site the foot of the west face of the Sandia Mountains, which rises to an elevation of 3200 m (10 500 ft) from a base of 2133 m (7000 ft). This event was not sanctioned by the Balloon Fiesta, and many other balloonists had warned against attempting such an ascension because of the turbulent wind conditions that existed. Nevertheless, several pilots believed that, by taking off in a protected canyon area, they would be sheltered from the wind turbulence. A few balloons ascended. One balloon, which contained a pilot and a single passenger, rose to approximately 610 m (2000 ft) when spectators observed the envelope, severely buffeted by rotor

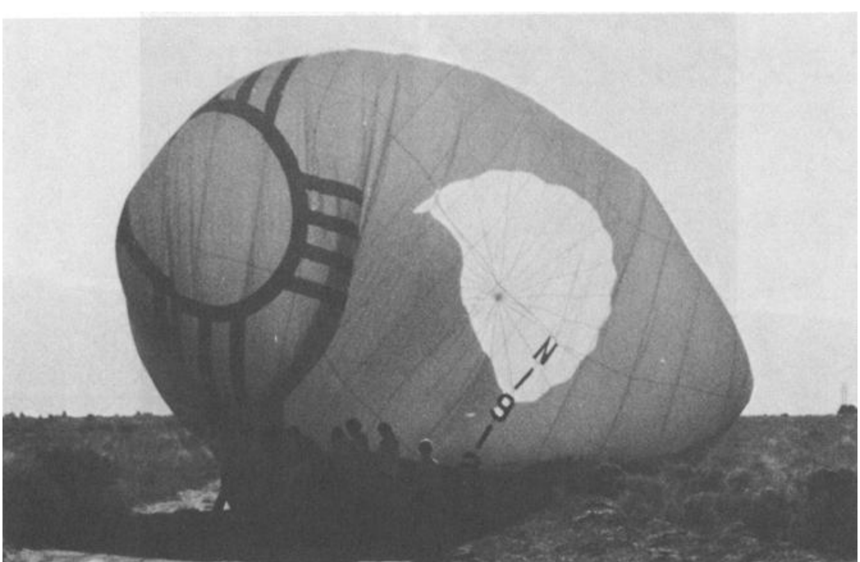

FIG. 6—*Deflation of Velcro fastened hot air balloon. Note shadow of opened top (courtesy of James Baldo).*

turbulence, to begin to collapse. The pilot attempted to maintain altitude by utilization of the burners. The top opened, tears developed in the fabric, and further burner blasts destroyed portions of the envelope. Large sections of fabric tore loose, and the balloon then descended at an uncontrolled rate (Fig. 7) and struck a blacktop road midway up the side of the mountain. Upon impact, the gondola burst into flames, and both individuals were found dead, completely charred (Fig. 8). The stainless steel propane tanks were found damaged but not ruptured. The pilot had multiple injuries resulting from the crash impact. No evidence of carbon monoxide was present in his blood, nor were alcohol or drugs found. The passenger was also observed to have multiple injuries and had a minimal carbon monoxide level of 8% with no alcohol or drugs present.

According to investigators [*4,5*], this fatal accident was a result of a combination of three factors. First of all, the balloon fabric was in extremely poor condition. It was noted to have rotted through in several areas, and it was believed that this caused the initial failure in flight, resulting in the deflation of the envelope. When the pilot attempted to maintain altitude, the burning of the throat of the envelope accelerated this collapse. That was pilot error.

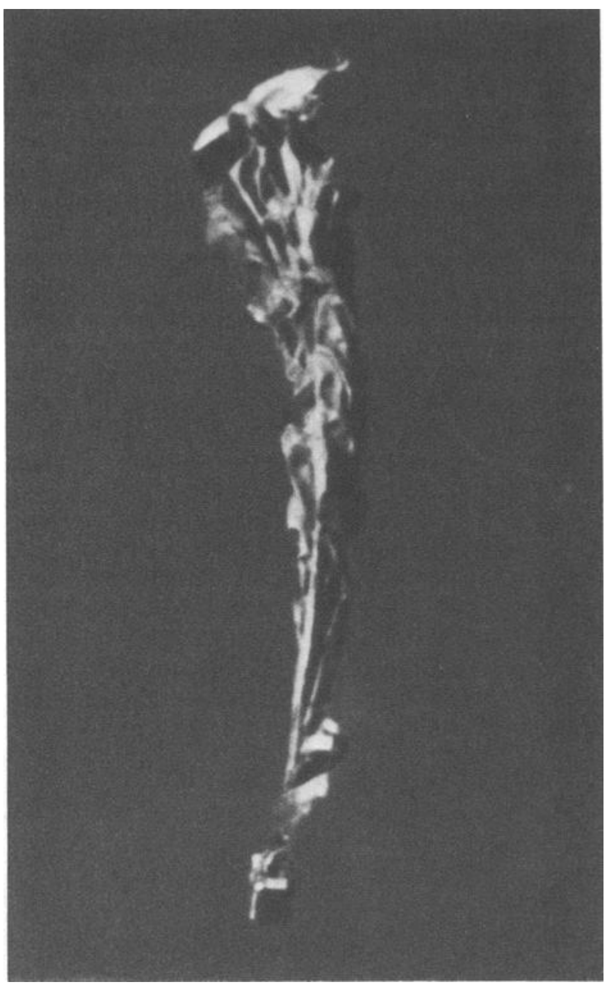

FIG. 7—*Balloon in Case 1 moments before striking ground (courtesy of Gary Tarter).*

FIG. 8—*Charred remains of gondola from Case 1 viewed by FAA examiner. Note structurally intact stainless steel horizontally configured propane tanks (courtesy of* Albuquerque Tribune*).*

Further, this pilot, with few flying hours to his credit and no experience in flying nonlevel terrain, should not have attempted this particular flight. The adverse weather conditions, consisting of severe wind turbulence, were recognized from the outset.

Case 2

During the Albuquerque International Balloon Fiesta in October 1982, a large balloon ascended in the early morning carrying a pilot and eight passengers. Two of the passengers were representatives of the balloon's manufacturer and, according to the FAA investigative report, had come to the Balloon Fiesta to observe problems with the balloon about which the pilot had complained on several occasions [6]. The initial portion of the flight took place without incident, and the pilot landed the balloon on a sandbar in the Rio Grande River so that a passenger could take pictures. After this photo session, the balloon took off from the sandbar, and the pilot informed the passengers they would be landing in an open field for the termination of the flight. As the pilot prepared to land, the gondola's bottom leading edge touched down, but, because the envelope remained fully inflated, the balloon lifted up slightly and touched down for a second time in an upright position.

According to survivors of the accident, along with other witnesses, the initial landing appeared to be normal. However, upon the second impact, liquid propane began escaping from the right front of the gondola. This was ignited by the pilot light of the burner, causing an explosion, and the gondola was engulfed in flames, resulting in extensive damage to the gondola and lower section of the envelope (Fig. 9). The pilot and four passengers were thrown out or jumped out of the balloon while it was still on the ground. This loss of weight

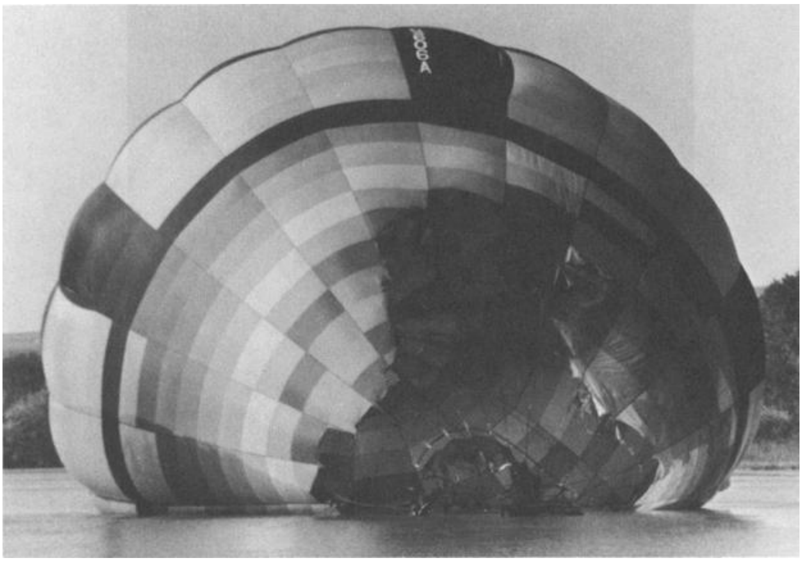

FIG. 9—*Balloon in Case 2 after landing in river. Note large hole burned in lower envelope (courtesy of Matthew Keith).*

caused the balloon to rise rapidly, and two passengers who were attempting to exit hung on until they let go at approximately 30 m (100 ft). The English balloon expert, together with his coworker, a balloon seamstress, were the last ones to exit the balloon at approximately 180 m (600 ft).

The investigation by the Federal Aviation Administration was unable to determine whether a line or a fitting in the fuel system had failed, causing the pressurized liquid propane to escape into the gondola (Fig. 10). Laboratory analyses showed that the fittings and hoses normally carrying propane had overload failures in them, but there were no specific defects that would account for their failure. All four fatalities were a result of multiple injuries. Both the balloon expert and his coworker showed evidence of burning caused by the fire in the gondola. The burns evident on the former individual's face and hands were testimony to his attempt to stop the fire by some means, such as dumping the propane tanks overboard. His carbon monoxide level was negative. In none of the four fatalities was alcohol found to be a factor.

Discussion

A perspective of the incidence of hot air balloon accidents can be gained by comparing the accident rate of hot air balloons with that of single engine aircraft. During the years 1975 to 1979, the average rate of accidents per 100 000-h flying time was 29.39 for balloons, more than twice the average rate of 12.54 for single engine airplanes [7]. Furthermore, the fatal accident rate of hot air balloons is also over twice the rate for single engine airplanes. These figures, although valid for comparisons of documented hours flown, may not be comparable as safety data for the following reasons:

1. The comparison of two sets of variables may be imprecise when the sample size of one is significantly different from the other; numbers of balloon hours are miniscule compared to fixed-wing hours.
2. Landings and take-offs are probably the most dangerous portions of any kind of flight,

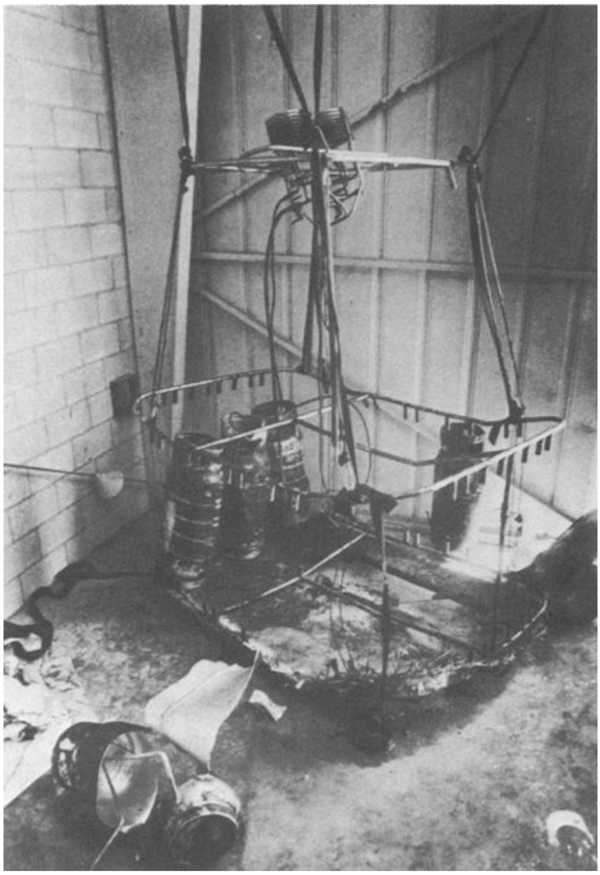

FIG. 10—*Gondola remains from Case 2. Note burst aluminum propane tank (courtesy of* Albuquerque Tribune*).*

and balloon flights are significantly shorter, on the average, than airplane flights; consequently, comparisons should be made of numbers of flights, as well as hours flown.

3. Balloon pilots are notorious for either exaggerating their hours logged or for not documenting them all.

Data from the Federal Aviation Administration revealed that between September of 1973 and July of 1983, 169 serious hot air balloon accidents occurred in the United States [7]. Of these 169 accidents, 21 accidents resulted in 42 fatalities. The hazards of hot air balloon flight that become factors in fatal accidents are discussed below.

Hazards of Hot Air Ballooning

Four specific factors that may pose a threat to the safety of hot air balloon enthusiasts are emphasized here.

Electrical Power Lines

These tend to be ubiquitous, high off the ground (often 27 m [90 ft] and more), and difficult to see, particularly if the tower span is great (more than 90 m [300 ft]) (Fig. 11). Infor-

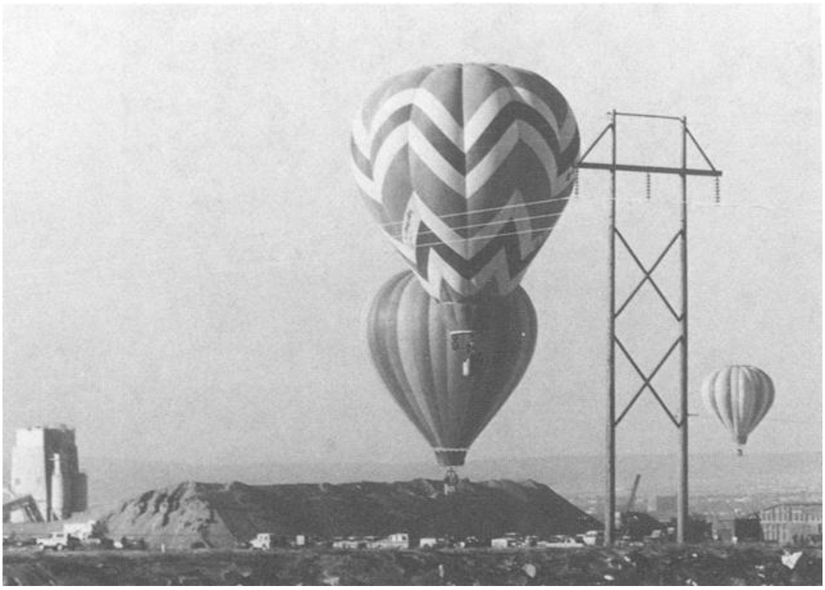

FIG. 11—*Hot air balloons in close proximity to 115 000-V power lines (photo by Dr. McConnell).*

mation received from Ernest Jenkins, Public Service Co. of New Mexico, reveals that voltage may vary from 440 to 115 000 V in regular transmission lines to 345 000 V in bulk transmission lines.[7] The ground or static wire is often located at the highest point on the tower. Arcing can occur between a static and hot wire, between two hot wires (two different phase wires), or between a hot wire and the earth or conductive objects affixed thereto, such as, towers or buildings. Arcing can cause propane hoses or tanks to rupture, metal cables to separate, or wet nylon to burn. Attempting to rise while flying into power lines will often draw the gondola up into the lines, because of the combination of balloon direction, curvature of the envelope below the equator, momentum, and lift. Experienced balloon pilots know the necessity for avoiding power lines [*8*], and, if they are unavoidable, to fly under them! (This means to land and deflate *before* the lines are contacted.)

Propane

This type of fuel is a three-carbon, extremely flammable hydrocarbon containing 25 403 kJ per litre (91 500 Btu per gallon) and is an odorless and colorless liquid below −42.2°C (−44°F) [*8,9*]. Propane is a gas at 869 kPa (126 psig) pressure at 20°C (68°F). Its vapor density is 1.6 (that is, propane is heavier than air in the gaseous state), and its specific gravity is 0.5 (that is, propane is lighter than water in the liquid state). Flammable limits in air are 2.2 to 9.5% by volume. Propane is scented with a foul-smelling mercaptan for safety purposes [*10*].

Two types of propane tanks are in common use: a 38-L (10-gal) aluminum, vertically oriented ("standup") tank (Fig. 12), and a 76-L (20-gal) stainless steel, horizontally configured ("lay-down") tank (Fig. 8). Tanks are equipped with pressure relief valves set at 2584 kPa (375 psig); this pressure corresponds approximately to a temperature of 71.1°C (160°F). Working pressure of these tanks is approximately 1654 kPa at 51.6°C (240 psig at 125°F).

[7]Ernest Jenkins, Public Service Co. of New Mexico, personal communication, May 1984.

FIG. 12— *Thirty-eight-litre (ten-gallon) aluminum vertically configured propane tank (photo by University of New Mexico Medical Illustrations).*

Hoses are relatively exposed but are somewhat protected by their attachments to the inside of the basket and superstructure. Every effort is made to protect all propane fittings, tubes, and valves from unexpected propane escape. Note that pilot light(s) are always ignited during the period between inflation and deflation to aid in quick burner ignition. While most propane fittings are steel, some are brass (brass is about half as strong as steel) [*8*]. The most potentially hazardous moments relating to propane are filling of tanks, landings (especially high wind or emergency landings), and any equipment failure or improper use.

Weather

This factor deserves special consideration because of its potential power, fickleness, and predictive inconsistency. Safest balloon flying conditions would be a windless, cool, early morning in a large valley with no frontal activity. Evening flight is not preferred only because the closer one comes to sundown while still in the air, the closer one comes to landing with inadequate visibility.

Frontal activity producing winds, sun-heated rising thermals, or other turbulence caused by winds over obstructions, downdrafts, adiabatic air mass activity, thunderstorms, rain, or snow constitute poor ballooning weather. An average flight may be 1 to 2½ h with no guarantee of landing at a predicted site. (The balloon moves with whatever air mass it is in, allowing no horizontal control over that movement except for being subject to the different directions of air masses at different altitudes.) The pilot must plan his or her flight using knowledge of predicted weather patterns, local meteorologic phenomena, potential changes in climate conditions, and good judgment.

Lift-off is not recommended in winds over 16.1 to 19.3 km/h (10 to 12 mph), and landing in winds over 24.1 to 32.2 km/h (15 to 20 mph) requires special skills and maneuvers, including quick deflation, all ignition and propane sources extinguished and secured, pressure relieved in all hoses, and physical precautions in order for passengers and pilot to stay in the basket safely without injury to bodies or equipment.

Wind shears or rotors (severe turbulence) occur at interfaces between masses of air moving at different velocities or directions.

Pilot

Six major areas where possible problems may relate to components of pilot competence versus incompetence are:

Training—Presently, a minimum of 8 h of training are required for a private balloon privilege and 35 h for commercial qualification (which also serves as the flight instruction certification). Training must be received from an FAA certified flight instructor, and there is mandatory passage of both written examination and flight test with a certified FAA examiner. Such flight instruction must be well organized, FAA certified, and provide for a logical progression of acceptable experience with ongoing evaluation.

Intelligence—The student and certified balloon pilot must have the ability to learn from didactic education and hands-on experience.

Judgment—The balloon pilot must be able to learn from personal as well as others' experiences, must have an appreciation and feel for spatial and temporal events as well as the intervals between them, and must deal with new situations in a calm but decisive manner. Proper flight planning is mandatory for a well-executed balloon flight. The sense of anticipating a maneuver well after the action that produces it is essential. One must practice and stay proficient in all phases of flight, including emergencies and unexpected contingencies. Above all, the pilot must be unaffected by peer pressure when his or her experience and judgment indicate otherwise. The balloon pilot must know and obey all FAA regulations.

Physical Ability—Keen senses, dexterity, strength, coordination, and reaction time are important physical capabilities.

Psychological State—Perhaps not separable from aspects of judgment, but other critical areas of concern are attitude (*machismo* has no place in flight planning or execution), mood (stability and psychological consistency are important), and self-assurance (the balloon pilot must be sure the decision made is correct, but the pilot must also take the position that, although there are risks in making a decision, there are more risks in not making a decision). The pilot must recognize his or her limitations as well as proficiencies; the pilot's panic limit should be set so high as to be unreachable in any circumstance.

Other—The most worrisome problems in this category relate to drugs and alcohol. As in other types of flying, these external phenomena may be related to many untoward consequences, including ballooning injuries and fatalities. Because ballooning is often a social sport, drinking spirits is prevalent among pilots, crew, and spectators (hopefully only *after* the flight). The most effective control on this behavior may be the restraint provided from within the social organization.

The legal questions that ensue from hot air balloon accidents are, for the most part, the same as those arising in other aircraft or motor vehicle mishaps. These include establishing who piloted the balloon, whether he or she was impaired by physical disease, alcohol, or drugs, and if so, did this contribute significantly to the accident.

For this reason, the pilot must be autopsied even though serious injuries are obvious at the scene. In Case 2, the original pilot had escaped the balloon when it touched down briefly. However, the person who remained in the gondola and, in effect became the pilot, was autopsied. Careful examination of the body revealed a pattern of burns consistent with his having attempted to expel the leaking propane tanks from the gondola, as had been described by several witnesses.

The other three victims in Case 2 were not autopsied, and none of the four had alcohol or carbon monoxide present on toxicological analysis.

Two of the victims, a husband and wife, had each been previously married, and a question arose on behalf of their respective estates regarding who died first. Since they had both fallen at the same time, with massive injuries resulting, the determination was made that they had died simultaneously.

Weeks after the accident, another question arose as to whether the wife had been pregnant as she had indicated to a relative. A pregnancy test was conducted on serum retrieved from samples taken for toxicological study at the time of the examination. The pregnancy test was positive.

A complete autopsy examination was also performed on the pilot of the balloon in Case 1. Aside from extensive impact injuries and charring of the bodies, no other underlying disease was found. No alcohol or drugs were found in the blood of either victim. The negligible carbon monoxide levels in the pilot and passenger indicated that death was due to the injuries rather than the fire.

As in other aircraft fatalities, samples for toxicological examination are provided to representatives of the Federal Aviation Agency. An effective working relationship with these experts in aircraft accident investigation is essential. They can assist the medical examiner in understanding the technical aspects of factors that caused or contributed to the accident.

This information, together with a basic knowledge of the construction of hot air balloons, weather conditions, and the facts gathered in the course of a thorough autopsy and toxicological examination, will allow the medical examiner to carry out a complete and competent analysis of this unique and dramatic type of accidental death.

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