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Causal factors of hot air ballooning incidents: identification, frequency and potential impact

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Abstract

Background: Hot air ballooning incidents are relatively rare, however, when they do occur they are likely to result in a fatality or serious injury. Human error is commonly attributed as the cause of hot air ballooning incidents; however, error in itself is not an explanation for safety failures. This research aims to identify, and establish the relative importance of factors contributing towards hot air ballooning incidents.

Methods: Twenty-two Australian Ballooning Federation (ABF) incident reports were thematically coded using a bottom up approach to identify causal factors. Subsequently, 69 balloonists (mean 19.51 years' experience) participated in a survey to identify additional causal factors and rate (out of seven) the perceived frequency and potential impact to ballooning operations of each of the previously identified causal factors. Perceived associated risk was calculated by multiplying mean perceived frequency and impact ratings.

Results: Incident report coding identified 54 causal factors within nine higher level areas: Attributes, Crew resource management, Equipment, Errors, Instructors, Organisational, Physical Environment, Regulatory body and Violations. Overall, 'weather', 'inexperience' and 'poor/inappropriate decisions' were rated as having greatest perceived associated risk.

Discussion: Although errors were nominated as a prominent cause of hot air ballooning incidents, physical environment and personal attributes are also particularly important for safe hot air ballooning operations. In identifying a range of causal factors the areas of weakness surrounding ballooning operations have been defined; it is hoped that targeted safety and training strategies can now be put into place removing these contributing factors and reducing the chance of pilot error.

Key words

balloonist, aviation, systems safety, accident analysis, human factors

Introduction

Although relatively rare when compared with commercial airplane incidents, within sports aviation the frequency of hot air ballooning incidents is second only to gliders [8]. Moreover, hot air balloon crashes are more likely to result in a serious or fatal injury than general aviation incidents. A recent US examination of National Transport Safety Board (NTSB) hot air balloon crash reports revealed that 83% of crashes result in fatality or serious injury [1]. A similar UK study reported 51% of ballooning incidents result in serious injury or fatality [13]. In contrast, only 4% of general aviation crashes are reported to result in injury [16]. Case studies of major hot air ballooning incidents indicate that the injuries sustained can be horrific, often as a result of blunt trauma from a fall with some instances of electrocution and/or burns following collision with power lines or fuel leaks [13, 18, 19]. Understanding the factors that contribute to ballooning incidents is therefore critical to inform the development of improved safety management strategies.

Epidemiological studies report that the majority of hot air ballooning incidents (81-88%) are attributable to pilot error [1, 6, 11]. However, most of those involved in accident research and analysis would argue that merely attributing accidents to human error is overly simplistic, as "…it is well established that accidents cannot be attributed to a single cause, or in most instances, even a single individual" [28]. Human error is not an explanation for failure [24]. Rather, accident analysis must take a systems approach to uncover the error-producing conditions present in the environment [9]. Despite this well accepted view, little is known regarding the underlying causes of pilot error during hot air balloon operations. Analyses of incident reports from the U.S. National Transportation Safety Board tend to focus on contextual factors (e.g. phase of flight, weather conditions) and the outcome of pilot errors (power line and fixed object strikes, nature of injuries). Typical recommendations from such analyses involve broad statements such as "improve object strike outcomes", "reduce landing-associated injuries" [1, 7], and "improve training" [6, 11]. While reducing object strikes and landing-associated injuries would, by definition, prevent the incident itself, such statements provide little insight into exactly *how* these objectives can be achieved. Moreover, the statement “improve training” leaves open whether it is the content, the structure or the delivery that requires improvement.

The limitations associated with recommendations generated from post hoc analysis of accident data are largely attributable to the nature of the original hot air balloon accident reporting protocol. Firstly, if the form for recording an aviation accident centrally standardised for all types of aviation this can make it hard to apply each field of the report to the non-motorised aviation of hot air ballooning [1]. Secondly, a narrow picture of causal factors may be generated if accident report forms require only the primary causal factor to be reported [25]. Thirdly, if the person completing the accident report form is not trained in systems accident analysis they are unlikely to identify factors outside the immediate context of the accident [26]. Finally, accident reports only include details of incidents which have been deemed serious enough to investigate. Near misses occur with greater frequency than accidents, and present opportunity to identify causal factors and design countermeasures to prevent their future occurrence [17].

The Australian Balloon Federation (ABF) has conducted investigations into all incidents reported to them by their members since 2009. The ABF is responsible for the administration and management of recreational hot air ballooning, under guidance and support from CASA [5]. Pilots must be a member of the ABF and have a recognised qualification to legally fly a hot air balloon for recreation in Australia, or to obtain a commercial license. The ABF encourages members to report any incident resulting in an adverse outcome (i.e. loss of control, collisions or injury), and serious errors or mishaps that have the potential to cause an adverse outcomes but fail to do so because of chance or because it is intercepted (near misses).

The ABF’s investigations are based on Reason’s [23] well known “Swiss Cheese” model of accident causation. The model considers active failures (i.e. unsafe acts and pre-conditions for unsafe acts), latent failures (i.e. pre-conditions for unsafe acts, unsafe supervision and organisational influences), and failed or absent defences. This model underpins the most widely used method for aviation accident analysis, the Human Factors Analysis and Classification System [27,28]. The investigations are conducted by an experienced balloon pilot (22 years' experience), with a background in accident investigation and human factors, who currently holds the role of National Safety Officer within the ABF. Although only a small number of investigations have been undertaken to date, this data potentially provides a rich source of information on the underlying causes of hot air balloon incidents.

The aim of this research is to identify and establish the relative importance of factors that contribute to incidents during ballooning operations to inform the development of safety management strategies. In Stage 1, contributing factors were identified from ABF investigation reports. Given that hot air balloon incidents occur relatively infrequently [8], pilot and crew perceptions of causal factors potentially represent another valuable source of information for improving safety management. Therefore, in Stage 2, a survey of Australian balloonists was undertaken to establish the relative perceived frequency and perceived impact of the identified factors, and to determine whether any other factors are thought to contribute to incidents during balloon operations.

Method

The study protocol was approved in advance by Monash University Human Ethics Committee. Each subject was provided with information about the study, submitting the completed online questionnaire was accepted as indication of consent to participate in the project. The identification and ranking of the factors that contribute to incidents during ballooning operations involved a two stage process. First, a thematic analysis of the ABF's incident investigation reports was undertaken. Second, the identified set of factors was presented to a group of hot air balloonists to obtain consensus views on their relative frequency and importance during balloon operations.

Procedure Stage 1

The first stage of the procedure was a thematic analysis of the ABF's investigation reports. As part of their commitment to safety the ABF encourages members to report all incidents in an online incident reporting database. An online tool (funded by CASA but developed and maintained by a private, independent aviation safety organisation) for confidential incident reporting is accessible to all members for self-completion, or members may contact the National Safety Officer to complete an incident report on their behalf. All incidents are investigated by the National Safety Officer who interviews the pilot and anyone else involved. In the case of major incidents the crash site may be visited and damaged balloon inspected. The ABF incident investigation is structured around identification of causal factors at multiple levels within the system, culminating in the production of recommendations to avoid a similar incident in the future.

Twenty two de-identified Australian Ballooning Federation (ABF) incident investigation reports were analysed. These represented all incidents which had been reported following the introduction of the ABF investigation report. The ABF incident investigation reports are for recreational hot air balloon incidents, no commercial hot air ballooning incidents were considered. Each report consisted of a synopsis of the incident, the investigator's incident analysis, findings and recommendations. Information identifying the pilot and aircraft were removed prior to the reports being provided to the research team. All incidents occurred between March 2009 and October 2012. A summary of incident characteristics identified from the synopsis are presented in Table i.

Table i: Characteristics of the ballooning incidents detailed in the ABF incident reports

Characteristic		Number of incident reports
Phase of flight	Inflation	5
	Ascent	1
	Approach (descent)	4
	Landing	4
	Deflation	2
	Tethering	1
	Pre/post flight	5
Injuries	None	21
	One person (minor)	1
Balloon damage as a result of incident	None	13
	Minor	8
	Major	1
Collision/near miss collision object	No collision	11
	Fence	3
	Powerline	1
	SWER	3
	Ground	2
	Trees	2
Student pilot	Student pilot	5
	Fully qualified pilot	15
	Not applicable	2

The incident investigation reports were coded using a bottom up thematic approach (adapted from [3]). This approach was taken because no existing taxonomy of causal factors of hot air ballooning incidents exists. Within general motorised aviation HFACS [27] is arguably the most widely used accident causal factor taxonomy. However, HFACS has been found to be inappropriate in other non-motorised sports aviation applications [15]. HFACS has also received some criticism in terms of the coding system being too coarse for the purposes of detecting specific operational problems or suggesting specific interventions for those problems [2, 20].

The bottom up thematic coding approach taken in the current study involved descriptively coding the text into themes to develop a coding template. Initially all causal factors were identified; for example, the statement “the pilot failing to direct the crew to keep ‘hands on’ until the final deflation activity had commenced.” was coded as causal factor “Poor crew resource management”. Often statements were transformed directly into coded themes. For example, “the pilot in command failed to follow the procedure”, was all coded as “Failure to apply correct procedure”. All information within the incident investigation report were coded (apart from the recommendations) to identify multiple causal factors leading to each incident. This inclusive approach was taken to establish the range of causal factors in hot air balloon incidents. The resulting codes were reviewed independently by two researchers to ensure they were distinct from each other, and classified into higher level areas by grouping causal factors representing similar themes.

Procedure Stage 2:

The second stage of the procedure was a survey of ABF members. A survey of ABF members was undertaken to establish perceived associated risk of each causal factor identified from the incident reports. The survey was designed to take approximately 20 minutes to complete. Initially, respondents were asked for basic demographic information and details of their involvement in ballooning. The next section presented the causal factors identified from incident reports and asked participants to report any causal factors which were not in the original list.

The last two sections of the survey listed each of the causal factors identified from the incidents. First, respondents rated how frequently each causal factor contributes to near misses and incidents during ballooning operations using a 7 point scale (1 = extremely infrequently, 7 = extremely frequently). Second, causal factors were then relisted and participants rated the perceived potential impact on ballooning operations that each causal factor would have if it occurred, using a 7 point scale (1 = no impact at all, 7 = severe impact).

An invitation to participate in the survey was sent via e-mail to all 242 ABF members, outlining the overall aims of the study, contact details of the lead investigator, and a hyperlink to the online survey location. The host website allowed one survey response per computer by placing a cookie on the participants browser at survey completion. If participants subsequently tried to complete the survey again they would receive a message to say it had already been completed. The survey remained open for three months. A reminder email was sent to ABF members one month after the initial invite. ABF members were able to pass the survey link on to non-ABF crew members who wished to participate. .

Statistical analysis

Frequency counts of incident reports containing each causal factor were undertaken. Descriptive statistics (mean, standard deviation and range) portray the demographics of survey respondents. Means and standard deviations of the perceived frequency and perceived impact ratings (out of 7) for each causal factor were calculated. Perceived associated risk was established by multiplying mean perceived frequency ratings by mean perceived impact ratings; causal factors were subsequently listed in order from most to least perceived associated risk.

Results

During the bottom up thematic coding of ABF investigation reports 208 separate codes were identified from the 22 incident investigation reports. Following combination of similar factors, these codes were condensed into 54 distinct causal factors. Thematic grouping identified nine higher level themes, each with a number of specific causal factors: Equipment (5 causal factors), Physical Environment (6 causal factors), Personal Attributes (10 causal factors), Crew Resource Management (1 causal factor), Errors (13 casual factors), Violations (2 causal factors), Instructors (4 causal factors), Organisation (6 causal factors) and Regulatory bodies and associations (7 causal factors). The full list of causal factors and the number of incident reports they occur in are provided as online supplemental material Table i.

Seventy participants started the survey for ABF members (28.9% of ABF memberships); one participant was excluded as they failed to answer any questions. The remaining 69 survey respondents (11 female) were experienced balloonists having been involved in ballooning for a mean of 19.51 years (SD 11.19, range 1y – 47y), flying for an average of 44.16h in the past 12 months (SD 52.05, range 0 – 215h). This is generally representative of the source population of ABF members, 15% of whom are female. The ABF does not keep records of years members have been involved in ballooning but it does record the hours pilot members fly each year. For the calendar year 2013 pilot members flew a mean of 49.51 hours (SD 61.6, range 0 – 266h). The majority of participants (75.3%) were aged between 35 and 64 years. The distribution of ages, ballooning experience and flying hours in the previous 12 months is presented in Table ii. Participants were asked to identify what roles they played within ballooning (as many as applied to them). Sixty participants (87%) reported being a balloon pilot (compared with 79% of ABF members). Half of the pilot participants held a commercial licence (n = 30, 42.9%) (compared with 28% of ABF members). Nine (13%) were student pilots (compared with 15% of ABF members). Twenty four of the pilots were also instructors (34.3%; compared with 12% of ABF members) and six of the instructors were also examiners (8.6%; compared with 9% of ABF members). Although, survey participants were representative of the ABF membership in terms of proportion female, flying hours in the past 12 months and age distribution, pilots were more likely to participate and instructors were over represented.

Table ii: Age, ballooning experience and recent flying hours distribution of survey participants and the source population (ABF membership).

Age group	n of survey participants	Proportion of survey participants	Proportion of ABF membership
18 to 24 years	7	10.1%	5.4%
25 to 34 years	2	2.9%	6.2%
35 to 44 years	14	20.3%	22.0%
45 to 54 years	23	33.3%	24.9%
55 to 64 years	15	21.7%	22.8%
65 to 74 years	8	11.6%	14.1%
Ballooning experience	**n of survey participants**	**Proportion of survey participants**	**Information not held by ABF**
1 to 5 years	7	10.1%	
6 to 10 years	11	15.9%	
11 to 20 years	23	33.3%	
21 to 30 years	18	26.1%	
31 to 40 years	7	10.1%	
41 to 50 years	3	4.3%	
Flying hours in previous 12 months	**n of survey participants**	**Proportion of survey participants**	**Proportion of ABF membership (pilots only)**
0 to 10 hours	18	26.1%	33.9%
11 to 20 hours	14	20.3%	16.4%
21 to 40 hours	16	23.2%	10.2%
41 to 60 hours	5	7.2%	5.6%
61 to 100 hours	6	8.7%	8.5%
101 to 200 hours	8	11.6%	14.1%
Over 200 hours	2	2.9%	6.2%

Ten additional causal factors were identified by survey participants, which could be categorised according the following higher level themes from the original analysis: Attributes (4), Crew Resource Management (2), Physical Environment (2) and Regulatory Body (2). The additional and updated causal factors are presented in Table iii along with the number of participants who identified each factor.

Table iii: Additional causal factors identified and the number of survey respondents identifying each factor. * denotes update to an existing causal factor.

Higher level theme	Causal Factor	Example	# participants identified by
Attributes	Poor health	Pre-existing medical condition, suffering from illness	2
	Peer pressure	'following others' (if he's flying; must be OK for me to 'embarrassment' i.e.: if I don't fly I may be poorly judged by others	2
	Rushing	Attempting to complete tasks quicker than is necessary	1
	Risk tolerance	An individual's attitude to risk – risk takers or risk averse.	2
Crew Resource Management	Inadequate ground crew training	Ground crew are poorly trained or briefed	3
	Insufficient crew	Insufficient number of people to safely launch.	1
Physical Environment	Ground objects	Fences, vehicles, buildings, people on launch/landing ground	7
	Terrain	Lack of available landing sites in direction of flight, flying in valleys and hilly terrain (potential for curl over).	4
Regulatory body	Poor/lack of guidelines regarding pilot ongoing professional development	Pilots who still lack some skills and have inadequate opportunity for future development	1
	Regulations are difficult to understand	Regulations are difficult to find and/or interpret.	2
	Regulatory bodies (e.g. ABF; CASA) poor/lack of safety guidelines/procedures*	Even if all safety guidelines were followed the situation would not be safe	3

Perceived associated risk to hot air ballooning operations was calculated (perceived frequency x perceived impact) to provide an indication of relative importance for each factor. Causal factors with high perceived impact which happen frequently are a greater risk to ballooning operations that those factors with low perceived impact that happen infrequently. These calculated ratings of perceived associated risk are based on responses from 48 participants who provided complete perceived frequency and perceived impact ratings for all causal factors. Table iv shows results for the 40 causal factors rated as having greatest perceived associated risk to hot air ballooning operations. Full ratings for all causal factors are presented as online supplemental material Table ii.. The causal factor calculated as having the greatest perceived associated risk is the physical environment factor of ‘weather’, followed by the attribute ‘inexperience’ and the error ‘poor/inappropriate decision’. The ten causal factors with greatest perceived associated risk fit within the higher level themes: “Errors”, “Attributes” and “Physical environment”.

The mean ratings for the perceived frequency of causal factors can be seen in Table iv and online supplemental material Table ii. The causal factor rated as occurring most frequently is ‘weather’, followed by ‘poor/inappropriate decision’ and ‘inexperience’. The ten causal factors rated as occurring most frequently are all fit within the higher level themes “errors” and “attributes” apart from ‘weather’. ’Inappropriate landing areas’ and ‘lack of recent experience’ were rated within the top ten most frequently occurring causal factors, however, they are not among the ten causal factors with greatest perceived associated risk, due to relatively lower perceived impact ratings.

The mean ratings of perceived impact of causal factors can be seen in Table iv and online supplemental material Table ii. The three causal factors which were rated as having the greatest perceived impact were all fit within the higher level theme “physical environment” (e.g. ‘single wire earth return (SWER)’, ‘powerlines’ and ‘weather’). The ten causal factors rated as having greatest perceived impact to ballooning operations fall within five higher level themes (3 “Physical environment”, “Errors”, “Equipment”, “Attributes” and “Instructor”). ‘Failure to provide adequate training’, ‘poor equipment maintenance’ and ‘equipment failure’ were amongst the ten causal factors rated as having greatest perceived impact, although these were not in the ten causal factors with greatest perceived associated risk, due to relatively lower perceived frequency of occurrence.

Table iv: Forty causal factors of hot air ballooning incidents with greatest perceived associated risk (perceived frequency x perceived impact; out of 49). Mean perceived frequency and perceived impact (out of 7) and standard deviations (SD) are presented. * denotes within the 10 causal factors rated as occurring with most perceived frequency, † denotes within the 10 causal factors rated as having most perceived impact if they were to occur.

Causal Factor (most to least perceived associated risk)	Higher level theme	Associated risk (Frequency x impact)	Frequency (mean)	Frequency (SD)	Impact (mean)	Impact (SD)
Weather conditions*†	Physical Environment	27.54	4.62	1.72	5.96	1.14
Inexperience*†	Attribute	25.78	4.47	1.67	5.77	1.11
Poor/Inappropriate decision*†	Error	25.25	4.55	1.78	5.55	1.19
Single Wire Earth Return (SWER)†	Physical Environment	24.49	3.85	1.97	6.36	1.15
Action performed too late*†	Error	24.20	4.36	1.58	5.55	1.18
Distraction*	Attribute	23.98	4.47	1.76	5.36	1.28
Inattention*	Attribute	23.36	4.34	1.83	5.38	1.26
Failure to adapt to or consider changing environmental conditions*†	Error	23.17	4.19	1.72	5.53	1.14
Power lines not SWER†	Physical Environment	22.38	3.57	1.75	6.28	1.19
Complacency*	Attribute	22.06	4.3	1.79	5.13	1.39
Inappropriate landing area*	Error	21.15	4.06	1.68	5.21	1.41
Incorrect diagnosis of problem/situation	Error	20.61	3.75	1.72	5.49	1.23
Failure to perform a complex manoeuvre	Error	20.25	3.79	1.69	5.34	1.17
Lack of recent experience*	Attribute	19.42	4.08	1.65	4.77	1.42
Failed to use all information available	Attribute	18.87	3.92	1.72	4.81	1.62
Misperception of your own skill level	Attribute	18.73	3.81	1.83	4.91	1.50
Inappropriate flight path	Error	18.68	3.74	1.63	5.00	1.46
Failure to provide adequate training†	Instructor	17.79	2.64	1.56	4.57	1.68
Instructor lack of skills	Instructor	17.37	3.13	1.69	5.68	1.25
Stress	Attribute	17.31	3.7	1.73	4.68	1.46
Failure to perform a routine manoeuvre	Error	16.86	3.36	1.69	5.02	1.33
Poor safety culture	Regulatory Body	16.82	3.08	1.69	5.47	1.35
Inadequate training program	Organisation	16.56	3.15	1.68	5.26	1.39
Failure to complete pre-flight preparation	Error	16.49	3.15	1.87	5.23	1.54
Fatigue	Attribute	16.20	3.34	1.82	4.85	1.53
Poor equipment maintenance†	Equipment	16.12	2.92	1.64	5.51	1.53
Misperception	Error	16.09	3.3	1.74	4.87	1.44
Poor lighting conditions	Physical Environment	15.98	3.17	1.85	5.04	1.67
Trees	Physical Environment	15.79	3.45	1.69	4.57	1.58
Instructor poor decision	Instructor	15.79	2.92	1.49	5.21	1.21
Not familiar with equipment	Error	15.54	3.02	1.72	5.15	1.44
Planned inappropriate operations	Organisation	15.41	2.94	1.74	5.23	1.34
Instructor assumption about skill level of student	Instructor	15.24	2.64	1.61	4.45	1.79
Inappropriate deflation location	Error	15.22	3.49	1.89	4.36	1.47
Lack of consensus regarding boundaries of safe operations	Organisation	15.00	3.00	1.83	5.00	1.59
Equipment failure or malfunction†	Equipment	14.78	2.49	1.54	5.94	1.42
Equipment used incorrectly pre-flight or during flight	Equipment	14.71	2.81	1.59	5.23	1.42
Regulatory bodies (e.g. ABF; CASA) poor/lack of guidelines regarding instructor training program and ongoing professional development	Regulatory Body	13.81	3.08	1.94	4.49	1.67
Poor communication between pilots and those in a supervisory role	Organisation	13.64	2.98	1.61	4.57	1.41
Regulatory bodies (e.g. ABF; CASA) poor/lack of guidelines regarding pilot training program	Regulatory Body	13.56	3.09	1.82	4.38	1.66

Discussion

Previous research investigating hot air ballooning incidents has focused either on national accident report databases [e.g. 1, 6, 7] or incident cases studies [12, 18, 19]. While such investigations provide important insight into the epidemiology of hot air ballooning they provide limited evidence regarding the underlying causal factors that lead to incidents. The current study addresses this gap by identifying the range of causal factors identified in a series of hot air ballooning incident investigations, as well as investigating their perceived associated risk. Firstly, a bottom up thematic coding technique was used to identify the causal factors considered in ABF held incident investigations. Secondly, a survey of experienced balloonists was undertaken to determine the perceived relative importance of each causal factor. Fifty four causal factors were identified from 22 incident reports, representing nine higher level themes: Attributes, Crew resource management, Equipment, Errors, Instructors, Organisational, Physical Environment, Regulatory body and Violations. The causal factors identified as having greatest perceived associated risk were: 'weather', 'inexperience' and 'poor/inappropriate decisions'.

The current research identified the higher level theme "Error" 38 times across 22 investigations, which is consistent with the view that most hot air balloon incidents [1, 6, 11] involve human error. With regards to the specific causal factors, the errors most frequently identified were 'poor/inappropriate decision' (8 incidents) and 'failure to perform a routine manoeuvre (6 incidents). 'Poor/inappropriate decision' was also perceived as a key issue by participants, who rated it as having a relatively high frequency and impact compared to other factors. In six of the investigations, 'poor/inappropriate decision' referred to on-the-spot decisions where a riskier option was selected when the investigator was able to identify a potential safer option (e.g. ascend rather than descend in response to contact with a powerline). This highlights one potential limitation of investigation reports: the "safer" option may have been obvious to the investigator in hindsight, but not to the pilot at the time of the incident.

The results also highlight many additional factors that potentially provide further insight into the underlying causes of such errors. For example, the theme "Physical Environment" was identified in 24 times across 22 investigations. Weather conditions (11 incidents), poor lighting conditions (4 incidents) and power lines not SWER (4 incidents) were the most frequently occurring factors within this theme. The causal factor identified as having greatest perceived associated risk was the 'weather'; it was rated the most frequently occurring causal factor and as having the third greatest perceived impact. Weather has been reported by others as a leading causal factor in hot air ballooning incidents [e.g. 1, 6, 13]. The wind was the most mentioned weather type. Specifically, changes in wind direction and/or speed, particularly light winds, wind shear and difficulty in predicting the wind were identified as being associated with incidents. These changes in conditions clearly link to different error types identified in the data (e.g. 'failure to adapt to or consider changing environment' and 'action performed too late'), which were perceived as a relatively high perceived risk compared to other factors. These findings reflect the vulnerable non-motorised nature of hot air ballooning as aviation. Pilots control a balloon by heating or releasing air in the envelope (canopy section of the balloon) to adjust aircraft height and do not have dynamic steering control (for a full description of the anatomy and physiology of hot air ballooning see McConnel et al., [19].). There is a delay between pilot action and response of the balloon. If the 'weather' changes, pilots 'failure to adapt to changing situations' or an 'action is performed too late' consequences will be further exacerbated by the delayed response of the balloon to any action/correction.

Exposure to, and the risks associated with, aspects of the physical environment can be addressed through pre-flight planning. Weather is a large part of pre-flight planning; pilots expend considerable effort examining weather forecasts and then assessing the weather once they arrive at launch sites. Pilots must be able to predict how weather patterns will influence balloon flight. Potentially, the documentation of decision rules relating to weather forecasts and the interaction of weather with other factors (e.g. wind speed and terrain of potential landing sites), particularly during marginal weather conditions, could assist pilots' planning. 'Powerlines' have previously been identified as dangerous for balloons, and collision with powerlines increases the risk of fatality [1]. Within rural Australia single wire powerlines (SWERs) are common as they provide a cheaper way to administer power to remote areas than standard 'powerlines'. The rural nature of ballooning makes them a common concern for Australian balloonists'. In the current study, only three incident reports included a 'SWER' and four others, standard 'powerlines'. Consistent with this finding, while neither 'SWERs' nor 'powerlines' were considered as frequent causal factors of hot air ballooning incidents, they were rated highly in terms of perceived impact. 'SWERs' were rated as having a greater associate risk than 'powerlines', this is likely because a single wire is harder to see from the air than multi wire, standard 'powerlines'. As collision with either a powerline or SWERS have such great potential consequences it would be advisable for pilots to have a pre-discussed plan with the crew about what to do if it happens. If a pilot identifies that striking a powerline/SWER is unavoidable they should descend as quickly as possible by releasing hot air from the top of the envelope. By descending the contact point will be higher up the balloon and further from the pilot, passengers and gas. As this type of decent needs to be much faster than in typical ballooning operations it would be beneficial for pilots to practice this. Planning may also include briefing passengers and crew particularly about staying in the basket unless there is an in-basket fire, phoning the power company, and not touching the powerline/SWER or anything in contact with it. A further component of planning would be to mark SWERs and powerlines onto the flying map of the pilots most frequently flown in area.

Another factor potentially related to pilot error is 'inexperience'. Three incident reports included 'inexperience' as a factor, within these lack of confidence was noted as well as more general inexperience. In contrast, participants considered 'inexperience' to be both frequent and of high perceived impact. However, it has been reported that the majority of hot air ballooning accidents occur with experienced pilots in command e.g. 100+ hours experience and that few student pilots have crashes [7]. These findings suggest that the early period of flying is the safest. A similar anecdotal view was held within the gliding community, however, this has recently been disproved by taking exposure rates into consideration [14]. Using log sheets to estimate flying exposure Jarvis and Harris [14] demonstrated that the most inexperienced glider pilots (10 hours of less) had twice the number of accidents per launch as more experienced pilots, despite being involved in a lower proportion of incidents than experienced pilots. These findings have implications for hot air ballooning incident reporting. Currently, exposure rates are not reflected in incident reports and therefore 'inexperience' is an important causal factor which could potentially be overlooked if incident data is considered in isolation. However, it should also be noted that inexperience is not only about absolute number of flying hours. Pilots with many previous flying hours may find themselves in an unfamiliar situation or flying area, and consequently experience an incident.

Despite its perceived associated risk, 'inexperience' is a phase which all pilots must go through. Strong safety management would allow pilots to gain experience with minimal exposure to high risk situations. One way in which the ballooning community controls this is to limit exposure to high risk events such as mass assents at fiestas. For instance Pilâtre de Rozier Organisation who host the largest ballooning event in Europe, where up to 400 balloons may be expected to launch from the same air field, require participating hot air balloon pilots to have at least 50 hours of pilot in command experience as well as a minimum of three ascents in the three months prior to the event [21]. Similar practice occurs for the largest balloon meet in Australia where at least 50 hours of pilot in command experience is required to participate [22]. In a similar manner to a graduated car driving licence, which reduces crash rates in inexperienced drivers [10], the gradual introduction to higher risk ballooning situations has potential to also reduce crash rates. An extended hot air ballooning pilot training period has previously been recommended [11].

Additionally, the current study identifies instructor-related causal factors as having high perceived impact on ballooning operations. This suggests that instructors have strong potential for mitigating incidents. It may be possible to take advantage of this high perceived impact by furthering instructor involvement with ‘inexperienced’ but qualified pilots. Furthermore, ‘poor/lack of opportunity for pilot continued professional development’ was identified as an addiction causal factor by one of the survey participants, identifying further potential for an extended training/licensing program.

The attributes ‘distraction’ and ‘inattention’ were both identified as having high perceived frequency risk, and occurred in approximately 25% of investigation reports. These attributes are likely to exacerbate errors and are particularly important given the dynamic nature of the physical environment and the slow response of a hot air balloon to controls. Hot air ballooning passengers are in close contact with the pilot; this perhaps presents potential for greater distraction than in aircraft where pilots and passengers are separated. Additional forms of distraction are instruments in the basket. Standard hot air balloons have few instrument panels, however, potable technology is becoming commonplace. One technology with increasing popularity is a moving map displayed on a tablet computer or similar. This displays the balloons current position and anticipated future trajectory. Such portable technology is not strictly necessary for flight and as such maybe overlooked in training. However, use of a moving map could result in problems equivalent to a driver focusing on a GPS for information rather than the environment around them [4]. One possible approach to address this would be to accept that technology is used and identify the perceived impact of distraction within training to highlight its disadvantages as well as benefits.

Finally, the limitations of the current study should be acknowledged. Firstly, the number of incident reports was small limiting the potential for all causal factors to be identified. While additional causal factors were identified through the survey, it was beyond the scope of this study to assess the perceived risk of these additional factors. Secondly, the survey was limited to ABF members, who are largely pilots, which is reflected in the demographics of survey respondents. This lack of variety in the role of respondents within the ballooning context means it is not possible to compare results between groups, and that results may contain bias towards pilots’ point of view. Future research may wish to consider specifically targeting hot air ballooning ground crew and compare opinions of incident causation between pilot and non-pilot experts. This is perhaps more important for hot air ballooning than other forms of recreational aviation because the set up and retrieval of a balloon requires intensive active involvement from the crew. Thirdly, casual factors were identified from recreational hot air ballooning incident investigation reports. It is likely that additional factors may be important for commercial ballooning operations, in particular organisation and regulation bodies factors are likely to have greater influence. Such additional factors may be similar to the organisation factors in the HFACS taxonomy which was designed around commercial aviation. Future research may wish to consider differences between the causal factors of commercial compared to recreational hot air ballooning incidents. Fourthly, it is unknown how many ballooning incidents go unreported. Potential under reporting may have created selection bias within the incident reports. Lastly, while the process of ballooning is universal, there may be some factors which are specific to the Australian context. For example SWERs are common in Australia but may not be in other countries. Additionally, there are no internationally accepted rules for hot air balloon legislation which may influence “organisation” and “regulatory bodies” causal factors. Future research may wish to consider differences of importance of causal factors between countries.

The current study illustrates that pilot errors are only one type of causal factor involved in hot air balloon incidents, in addition to factors relating to pilot attributes, crew resource management, equipment, instructors, organisational aspects, the physical environment, regulatory body issues and violations. It is important that training and safety management consider both the causal factors which occur frequently and also those factors which occur rarely but have high potential impact. It is only through addressing the range of causal factors which potentially contribute to incidents, that we can reduce the chance of “pilot error” [23].

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Online Supplemental materials

Supplemental material Table i : Causal factors of hot air balloon incidents and the number of incident investigation reports each causal factor occurred in. * denotes the causal factors which occurred most frequently.

Higher level theme	Causal Factor	Example	# incident reports featured in
Attributes	Stress*	High workload/task overload	7
	Failed to use all information available*	Making decisions based on weather and personal preference but failure to take into account other factors such as time	7
	Complacency*	Flying a very familiar area; When reaching the end of a successful flight	6
	Distraction*	Talking to a passenger; Dealing with one problem and failing to notice another	5
	Inattention	Not noticing a change in altitude or not noticing another balloon when flying in a group	4
	Inexperience	New crew; Student pilot; First time experience of a particular situation; Flying at an event	3
	Age	Any age related decline such as impaired vision	2
	Misperception of your own skill level	Over confident; Under confident	1
	Lack of recent experience	Experienced person who had not been ballooning for a while	1
	Fatigue	Not enough prior sleep; Feeling increasingly tired the longer you spend on something	1
Crew Resource Management	Poor crew resource management*	Poor leadership; Poor communication; Poor delegation; Inappropriate allocation of tasks	6
Equipment	Equipment failure or malfunction*	Pilot light not igniting; Parachute Velcro tabs fail	8
	Poor design of equipment/not fit for purpose	Hard to access controls; Homemade trailer a very tight fit for balloon	3
	Poor equipment maintenance	Inadequate drying of envelope following getting wet	3
	Equipment used incorrectly pre-flight or during flight	Accidently turn gas tank off rather than on	2
	Lack of/missing equipment	First aid kit is missing; Lack of gloves	1
Errors	Poor/Inappropriate decision*	Adopted a risk option when a safer one was available	8
	Failure to perform a routine manoeuvre*	Inappropriate descent rate to land into a large open field	6
	Action performed too late	Burning too late to successfully ascend over an object	4
	Not familiar with equipment	Flight in a balloon not previously used	4
	Inappropriate landing area	Locked field; Crop field; Residential area; Dangerous location; Steep hill; Bog	3
	Failure to adapt to or consider changing environmental conditions	Not changing plans if there is an unexpected change in the weather	2
	Incorrect diagnosis of problem/situation	A problem with gas flow identified as being due to the gas tank when it is actually due to the gas line	2
	Inappropriate flight path	Not changing altitude when flying over horses	2
	Inappropriate deflation location	Location has a barbed wire fence	2
	Failure to complete pre-flight preparation	Check equipment prior to flight including prior to arrive at launch site; Planning does not take into account potential risks	2
	Passenger behaviour	Passengers do not adopt appropriate landing position	1
	Misperception	Failure to see/become aware of/understand importance of an object	1
	Failure to perform a complex manoeuvre	Landing under extenuating circumstance such as in a very tight landing space	1
Instructors	Instructor assumption about skill level of student	Instructor assumes students are capable of briefing crew	4
	Failure to provide adequate training	Instructor demonstrating an action but not allowing student to practice	3

	Instructor lack of skills	Although the instructor is a good pilot they have no teaching skills	2
	Instructor poor decision	Leaving it too late when taking over from student in dangerous situation	2
Organisational	Culture of hierarchy	Students not questioning instructors; Crew not questioning pilot decisions; Pilots following event managers decisions without question	3
	Inadequate training program	Training does not cover all situations	3
	Poor or ineffective inflight guidelines or procedures	Recommended emergency landing procedures insufficient	2
	Poor communication between pilots and those in a supervisory role	Safety manager at an event is not contactable; Pilots are unable to contact an ABF representative	2
	Planned inappropriate operations	Event launch site is not fit for purpose	1
	Lack of consensus regarding boundaries of safe operations	Disagreement between two pilots at an event or between pilot and crew regarding what is safe	1
Physical Environment	Weather conditions*	Wind; Turbulence; Mist	11
	Poor lighting conditions	Low sun making vision difficult	4
	Power lines not SWER	Presence of powerline making it hard to find a safe landing site	4
	Single Wire Earth Return (SWER)	A single wire and poles far apart makes it hard to see	3
	Animals in the environment	Distressed livestock ran into a fence	1
	Trees	Volume of trees make landing difficult; Trees create curl over	1
Regulatory body	Regulatory bodies (e.g. ABF; CASA) lack of safety guidelines/procedures*	Even if all safety guidelines were followed the situation would not be safe	5
	Regulatory bodies (e.g. ABF; CASA) poor/lack of guidelines regarding instructor training program and ongoing professional development	Instructors are fully trained under current regulations but still lack some skills and have inadequate opportunity for future development	4
	Poor ballooning event management	Event director fails to cancel flight in response to bad weather	3
	Regulatory bodies (e.g. ABF; CASA) poor/lack of guidelines regarding pilot training program	Even when all training requirements are fulfilled pilots lack knowledge or particular skills	2
	Poor safety culture	Individuals doing their own thing rather than following safety procedures/guidelines	2
	Civil Aviation regulations	Regulations for flying near airports are insufficient	1
	Media actions/reporting	Media misperception of ballooning leading to in-accurate media stories	1
Violations	Violations of regulatory body standards/guidelines*	Not obtaining landowner permission; Infringement of a prohibited zone (PZ)	5
	Failure to apply company procedures	Commercial balloon pilots making an inappropriate decision without contacting management	1

Supplemental material Table ii: Causal factors of hot air ballooning incidents in order of calculated perceived associated risk (perceived frequency x perceived impact; out of 49). Mean perceived frequency and perceived impact (out of 7) and standard deviations (SD) are presented. * denotes the 10 causal factors rated as occurring with most perceived frequency, † denotes the 10 causal factors rated as having most perceived impact if they were to occur.

Causal Factor (most to least perceived associated risk)	Higher level theme	Associated risk (Frequency x impact)	Frequency (mean)	Frequency (SD)	Impact (mean)	Impact (SD)
Weather conditions*†	Physical Environment	27.54	4.62	1.72	5.96	1.14
Inexperience*†	Attribute	25.78	4.47	1.67	5.77	1.11
Poor/Inappropriate decision*†	Error	25.25	4.55	1.78	5.55	1.19
Single Wire Earth Return (SWER)†	Physical Environment	24.49	3.85	1.97	6.36	1.15
Action performed too late*†	Error	24.20	4.36	1.58	5.55	1.18
Distraction*	Attribute	23.98	4.47	1.76	5.36	1.28
Inattention*	Attribute	23.36	4.34	1.83	5.38	1.26
Failure to adapt to or consider changing environmental conditions*†	Error	23.17	4.19	1.72	5.53	1.14
Power lines not SWER†	Physical Environment	22.38	3.57	1.75	6.28	1.19
Complacency*	Attribute	22.06	4.3	1.79	5.13	1.39
Inappropriate landing area*	Error	21.15	4.06	1.68	5.21	1.41
Incorrect diagnosis of problem/situation	Error	20.61	3.75	1.72	5.49	1.23
Failure to perform a complex manoeuvre	Error	20.25	3.79	1.69	5.34	1.17
Lack of recent experience*	Attribute	19.42	4.08	1.65	4.77	1.42
Failed to use all information available	Attribute	18.87	3.92	1.72	4.81	1.62
Misperception of your own skill level	Attribute	18.73	3.81	1.83	4.91	1.50
Inappropriate flight path	Error	18.68	3.74	1.63	5.00	1.46
Failure to provide adequate training†	Instructor	17.79	2.64	1.56	4.57	1.68
Instructor lack of skills	Instructor	17.37	3.13	1.69	5.68	1.25
Stress	Attribute	17.31	3.7	1.73	4.68	1.46
Failure to perform a routine manoeuvre	Error	16.86	3.36	1.69	5.02	1.33
Poor safety culture	Regulatory Body	16.82	3.08	1.69	5.47	1.35
Inadequate training program	Organisation	16.56	3.15	1.68	5.26	1.39
Failure to complete pre-flight preparation	Error	16.49	3.15	1.87	5.23	1.54
Fatigue	Attribute	16.20	3.34	1.82	4.85	1.53
Poor equipment maintenance†	Equipment	16.12	2.92	1.64	5.51	1.53
Misperception	Error	16.09	3.3	1.74	4.87	1.44
Poor lighting conditions	Physical Environment	15.98	3.17	1.85	5.04	1.67
Trees	Physical Environment	15.79	3.45	1.69	4.57	1.58
Instructor poor decision	Instructor	15.79	2.92	1.49	5.21	1.21
Not familiar with equipment	Error	15.54	3.02	1.72	5.15	1.44
Planned inappropriate operations	Organisation	15.41	2.94	1.74	5.23	1.34
Instructor assumption about skill level of student	Instructor	15.24	2.64	1.61	4.45	1.79
Inappropriate deflation location	Error	15.22	3.49	1.89	4.36	1.47
Lack of consensus regarding boundaries of safe operations	Organisation	15.00	3.00	1.83	5.00	1.59
Equipment failure or malfunction†	Equipment	14.78	2.49	1.54	5.94	1.42
Equipment used incorrectly pre-flight or during flight	Equipment	14.71	2.81	1.59	5.23	1.42
Regulatory bodies (e.g. ABF; CASA) poor/lack of guidelines regarding instructor training program and ongoing professional development	Regulatory Body	13.81	3.08	1.94	4.49	1.67

Poor communication between pilots and those in a supervisory role	Organisation	13.64	2.98	1.61	4.57	1.41
Regulatory bodies (e.g. ABF; CASA) poor/lack of guidelines regarding pilot training program	Regulatory Body	13.56	3.09	1.82	4.38	1.66
Culture of hierarchy	Organisation	13.42	3.02	1.63	4.45	1.63
Poor or ineffective inflight guidelines or procedures	Organisation	12.95	2.75	1.53	4.70	1.67
Poor crew resource management	CRM	12.19	3.00	1.66	4.06	1.59
Failure to apply company procedures	Violation	12.08	2.64	1.56	4.57	1.68
Regulatory bodies (e.g. ABF; CASA) lack of safety guidelines/procedures	Regulatory Body	12.00	2.70	1.56	4.45	1.70
Poor ballooning event management	Regulatory Body	11.78	2.47	1.51	4.77	1.63
Violations of regulatory body standards/guidelines	Violation	11.75	2.64	1.61	4.45	1.79
Lack of/missing equipment	Equipment	11.55	2.43	1.50	4.74	1.54
Animals in the environment	Physical Environment	10.41	2.81	1.59	3.70	1.49
Civil Aviation regulations	Regulatory Body	9.79	2.53	1.37	3.87	1.70
Media actions/reporting	Regulatory Body	9.68	2.58	1.75	3.74	1.85
Poor design of equipment/not fit for purpose	Equipment	9.57	2.00	1.19	4.79	1.65
Passenger behaviour	Error	8.84	2.42	1.60	3.66	1.51
Age	Attribute	6.68	2.43	1.53	2.74	1.37