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Cause Analysis of Unsafe Acts of Pilots in General Aviation Accidents in China with a Focus on Management and Organisational Factors

Abstract

Introduction: General aviation (GA) safety has become a key issue worldwide and pilot errors have grown to be the primary cause of GA accidents. However, fewer empirical studies have examined the contribution of management and organisational factors for these unsafe acts. The flawed decisions at the organisational level have played key roles in the performance of pilots. This study provides an in-depth understanding of the management and organisational factors involved in GA accident reports **Method**: A total of 109 GA accidents in China between 1996 and 2021 were analysed. Among these reports, pilot-related accidents were analysed using the human factors analysis and classification system (HFACS) framework. **Results**: The significant effects of managerial and organisational factors and the failure pathways on a GA accident have been identified. Furthermore, unlike traditional HFACS-based analyses, the statistically significant relationships between failures at the organisational level and the sub-standard acts of the pilots in GA accidents were revealed. **Conclusion**: Such findings support the GA accident prevention strategy that attempts to reduce the number of unsafe acts of pilots should be directed to the crucial causal categories at HFACS organisational levels: resource management, organisational process, failure to correct a known problem, inadequate supervision, and supervisory violations.

Keywords: general aviation accidents; HFACS; unsafe acts; organisational factors

1. Introduction

General aviation (GA) is inclusive of all civil aviation operations, apart from scheduled air transport, including search and rescue flights, air medical flights, crop dusting flights, flight training, and scientific experiment flights[1]. From 2011 to 2020, 94 GA accidents in China led to a death toll of 85. However, no accidents have been reported for scheduled air transport[2-7]. This outcome indicates that GA is a high-risk industry compared to scheduled air transport in China (see Figure 1). The development trend of GA accidents can also be observed in other countries. Given the fairly large number of fatalities and injuries caused by these accidents as well as loss of entrepreneurial production, GA accidents incur substantial costs to society. For example, Sobieralski [8] estimated the average annual GA accident cost in the United States to be between 1.64 billion USD and 4.64 billion USD. For Australia, the estimated total cost of GA accidents was 62.36 million USD in 2003, and New Zealand bore an annual accident cost attributed to GA between 9.74 million USD and 25.05 million USD[9,10]. The premiums earned by insurance companies always fail to cover the incurred losses related to GA accidents and incidents [11]. Therefore, reducing the number of GA accidents to ensure the sustainability of GA growth is an important safety challenge.

According to the International Civil Aviation Organisation (ICAO)[12], an analysis of previous accidents and incidents could help accident prevention effectively. Aircraft accidents culminate in a variety of precursive factors, including human error and technical or equipment malfunctions[13]. Although continued advances in aircraft design, reliability, and safety have substantially reduced accidents caused by the environment and equipment, human factors have played significant roles in aircraft accidents[14]. As is shown in Figure 2, in China, the proportion of civil aviation accidents directly related to mechanical breakdown has gradually decreased since 1995, while the percentage of accidents in which unsafe acts of aircrew were cited as direct causes has been on the rise. A plethora of studies has indicated that approximately 55 to 95% of GA accidents can be attributed, at least in part, to pilot errors[15-17]. In contrast to GA, only 38% of airline accidents exhibited a direct association with pilot errors [15].

The unsafe behaviour of pilots in GA accidents has received considerable attention from scholars. According to Wiegmann et al. [13], skill-based errors were observed in nearly 80% of pilot-related GA accidents, followed by decision errors and routine violations. Lenné et al. [18] evaluated human error in GA crashes and found that the unsafe acts of pilots, including skill-based errors and decision errors, were significantly associated with latent failures, including sub-standard personal readiness, physical/mental limitations, and adverse mental states of pilots. Bearman et al. [19] further pointed out that special situations (time constraints, financial pressures, lack of maintenance facilities, physical discomfort) can strongly influence pilots' decision-making. According to the statistics of reasons for GA pilots' unsafe acts between 2010 and 2019, situational awareness was the most observed reason, followed by insufficient rest, distraction in the cockpit, and navigational error [20]. Li et al. [15] concluded that instrument meteorological conditions (IMC), locations and aircraft types (helicopter and airplane) were associated with pilot errors.

However, there is little empirical work on the failures in organisations associated with the generation of unsafe acts of GA pilots. Dekker [21] proposed that human error is a symptom of failure deeper inside the organisational system. Organisational failures not only create conditions of human error but also have the potential to generate a working environment in which personnel are more likely to commit violations [22]. Orasanu and Connolly [23] emphasised that pilots' decisions were influenced by the organisation’s operating procedures in a direct way and by norms and culture in an indirect way. Gaur [24] and Li et al. [15] are two of the few studies that examine the influence of management and organisational factors on civil aviation accidents. Gaur found that over 50% of the civil aviation accidents examined had organisational influences. Li et al. analysed 41 civil aviation accidents that occurred in China. The results provided an understanding, based upon empirical evidence, of the impact of decisions at management level on the occurrence of unsafe acts of pilots such as poor resource management, inadequacies in organisational process, supervisory violations and inadequate supervision. Xue and Fu [25] emphasised the critical role of organisational factors in the violation operation of pilots based on a modified analysis model for GA accidents. By analysing 133 helicopter accidents that occurred in Brazil, Filho et al. [26] concluded that high-level management contributed to the chain of events leading to pilots' unsafe acts. Nonetheless, the proportion of helicopter accident reports in which organisational factors were described was small, which may be related to the fact that GA accident reports (especially non-fatal accidents) rarely capture organisational influences. Many studies have indicated that the lack of a systematic investigation of GA accidents and incidents was the key reason for the scarcity of research involving management and organisational factors associated with the performance of pilots [13,14,16].

According to Lenné et al. [18], understanding the nature of organisational factors is critical for safety programs to achieve greater success. Interventions at active failures of pilots only slightly affect GA safety unless there are effective supervisory and organisational processes in place to provide support. More importantly, interventions at the organisational level are likely to be the most cost-effective [27]. In this context, it is important to examine the organisational and management factors underlying GA accidents to develop effective safety programs and GA accident countermeasures. This study aims to reveal the contribution of management and organisational factors to the unsafe acts of GA pilots by describing the associations between causal factors at the organisational and operational levels. A human error taxonomy approach was used to accomplish this. To date, there have been very few studies that examined the impact of organisational levels on GA pilots' acts. Due to data constraints, those studies either failed to provide an in-depth analysis of organisational and management factors or did not distinguish between airline accidents and GA accidents. Our study bridges this gap with GA accident reports involving GA enterprises published by Civil Aviation Administration of China (CAAC). CAAC is responsible for GA accident investigation as well as GA aircraft operation supervision in China.

2. Analytical Framework

2.1. Human Factor Analysis and Classification System (HFACS)

Although many models have been proposed to analyse the human error in aircraft accidents, the Human Factors Analysis and Classification System (HFACS) is still the most popular aircraft accident model in the literature [27]. It is derived from Reason's organisational model of human error [28] and was originally designed for the investigation and analysis of US military aviation accidents [29]. As themes and trends in causal factors could be easily identified with this taxonomic approach, HFACS lends itself to multiple accident case analyses [30]. Table 1 shows the application of HFACS to various accidents that occur across different countries.

Following the cases of HFACS applicability and the nature of the HFACS framework, which considers failures at all levels of an organisation, HFACS was used as an appropriate analytical framework in this study to examine the failures at organisational levels, influencing the unsafe acts of GA pilots. According to the version of the HFACS framework described by Shappell and Wiegmann [31], the entire HFACS framework includes four levels and 19 causal categories. The four levels are listed in Table 2 and the HFACS framework is shown in Figure 3.

2.1.1. Unsafe Acts

Unsafe acts refer to the active failures of front-line pilots, which dominate most accident databases. Failures at this level can be classified into two categories; errors and violations. Errors (skill-based errors, decision errors, and perceptual errors) represent the unsafe acts that occur within rules and regulations implemented by an organisation, while violations (routine violations and exceptional violations) are defined as the wilful disregard for the rules and regulations which are more generally associated with motivational problems.

Skill-based errors are the failures of highly practiced behavior that occur with little or no conscious thought. Skill-based errors frequently appear as failure to see and avoid, breakdown in visual scan, and inadvertent use of aircraft. *Decision errors* are best described as “honest mistakes” and often occur in situations where pilots do not have the appropriate knowledge or choose a plan that proves inappropriate for the situation at hand. Although *perceptual errors* are generally less frequent in accident reports, they are as important as skill-based errors and decision errors. The type of error arises when pilots' perception of the world differs from reality such as misjudging the distance/altitude/airspeed.

Routine violations are defined as habitual acts which are often tolerated and, in effect, sanctioned by the system or administrations. Therefore, the occurrence of a routine violation is indicative that there might be failures in supervision level. *Exceptional Violations* are isolated departures from authorities. Unlike routine violations, exceptional violations are neither typical of the individual nor condoned by management.

2.1.2. Preconditions for Unsafe Acts

It is recognized that focusing on why unsafe acts occurred in the first place is a very important step in accident analysis. The process involves analysing preconditions for unsafe acts of pilots, which consists of environmental factors (physical environment and technological environment), the condition of pilots (adverse mental states, adverse physiological conditions and physical/mental limitations), and personnel factors (crew resource management and personal readiness).

Physical environment has been shown to have an impact on pilots, which includes the operational environment (i.e., adverse weather, altitude, terrain), and the ambient environment (i.e., temperature, noise, vibration, light, toxins) in the cockpit. The *technological environment* also has a tremendous impact on the performance of pilots. This category encompasses a variety of issues such as the design, display characteristics and automation of hardware and controls.

Adverse mental states can be understood as not being prepared mentally. The mental conditions that affect the performance of pilots are considered in this category (i.e., the loss of situational awareness, pernicious attitudes, task fixation). *Adverse physiological states* refer to the medical and/or physiological conditions of pilots, such as spatial disorientation, illness, intoxication, and poisoning known to impair the performance of pilots. *Physical and mental limitations* refer to the instances when operational requirements exceed the limit of the individual in the control of aircraft. For instance, pilots may find themselves in emergencies in which the time required to respond or choose an appropriate plan exceeds their ability.

Crew resource management is regarded as a cornerstone of aviation and used to account for the occurrences of poor coordination or communication among personnel. Deficiencies in the crew's cockpit and non-cockpit communications are the most common factors in this category. *Personal readiness* is the failure of individuals to prepare physically or mentally for duty. Unlike routine violation, this causal factor emphasizes failures of pre-flight preparation, such as drug use, alcohol consumption, violation of rest management, etc.

2.1.3. Unsafe Supervision

The category of supervision was considered in Swiss Cheese Model, which creates preconditions for unsafe acts and influences the condition of pilots and the type of environment they work in [31]. In the context of GA enterprises, supervision generally refers to the practice of deputy general manager of operation and maintenance. The situation where pilots own or lease aircraft and need to carry on self-supervision is not considered in our study. This category comprises four sub-categories: inadequate supervision, planned inappropriate operations, failure to correct a known problem, and supervisory violations.

Inadequate supervision refers to inappropriate oversight and management of resources and personnel. There are many examples in which the lack of supervision and oversight triggers the violations of crew as well as other unsafe acts[31]. One of the examples is supervisors of GA enterprises always failed to provide adequate recurrent training for pilots or ensure pilots have sufficient rest time between flights, skill-based errors are more like to occur. *Planned inappropriate operations* category contains errors in the task assignment by managers related to operations. A common error classified into this category is the improper manning. For example, senior, dictatorial captains are paired with junior, weak co-pilots or inexperienced flight instructors are paired with poorly trained student pilots, communication and coordination problems are more easily observed. *Failure to correct a known problem* refers to those instances when problematic issues are known to supervisors and they fail to correct them accordingly. For example, the failure to identify at-risk GA pilots who had repeatedly violated flight procedures. This kind of supervisory behavior is more likely to foster an unsafe atmosphere and then promote the violation of rules and regulations [31]. *Supervisory violations* are willful disregard for existing rules and doctrine by supervisors during the course of their duties, creating the preconditions for the tragic sequence of events that predictably follow. For example, the operation manager of GA enterprises arranges personnel to perform flight tasks without the necessary qualification and license, which creates the precondition of fatal pilot errors.

2.1.4. Organisational Influences

Organisational influences describe the contributions of flawed decisions in upper command levels, directly affecting the practices at the mid-management level, as well as the conditions and actions of front-line pilots. The upper command levels of GA enterprises refer to the upper-level management including the manager and deputy manager. This category can be examined into three subcategories: resource management, operational process, and organisational climate.

Resource management refers to corporate decisions on how to allocate, manage and maintain the organisational assets (personnel, monetary assets, equipment, and facilities). It is noteworthy that the financial performance of GA enterprises has a critical impact on the resource management decisions. For example, GA enterprises in times of fiscal austerity tend to purchase low-cost and less effective equipment which have a higher risk of accidents *Operational process* is defined as corporate decisions and rules governing the everyday activities of the organisation. Often, topics including operations (operational tempo, time stress, production quotas), procedures (standards, defined objectives, documentation) and oversight (risk management, safety programs) are covered in this category. In China, GA enterprises are more likely to be rated risky operators by CAAC if they fail to establish a potential safety hazard investigation and treatment system or formulate safety training program and annual safety training plan. *Organisational climate* can be viewed as the prevailing working atmosphere within the organisation which comprises a broad class of variables that influence personnel performance such as policies, command structure, and culture. Take command structure, for example, if the command-chain of GA enterprises is confusing and no one knows who is in charge, organisational safety will easily suffer and accidents happen.

3. Methods

3.1. Data Source

The 109 GA accident reports from the calendar years 1996–2021 were obtained from CAAC according to the following criteria;

Time interval: 1996–2021
Type of research: GA accident reports
Operation: GA enterprises

Aircraft Category: Fixed-wing aircraft, helicopters, and gyrocopters
Report Status: Final report
Injury Severity: Fatal and Non-fatal

CAAC clearly defined the investigation standard of civil aviation accidents in 1995. Thus, the GA accidents, which occurred between January 1996 and December 2021, were obtained for analysis. Additionally, this study was primarily interested in powered aircraft, and thus the data were restricted to include only accidents involving powered GA aircraft. Gliders, blimps, and balloons were excluded from the analysis. Ultra-light aircraft were also excluded [13]. Some of those reports, 16 in total, have provided only basic information, yet causal factors were not described, and consequently, were not considered. Ultimately, 109 final accident reports in which causal factors were identified and described in detail were submitted for further analysis. All GA accidents examined conformed to the accident definition in the 9th edition of Convention on International Civil Aviation, Annex 13[12] and the civil aircraft accident definition given in Civil Aircraft Accident Investigation Rules (CCAR-395-R2)[55].

3.2. Reliability Analysis

Among the 109 GA accident reports, coding has only been applied to 86 GA accidents where pilot error was involved. Two experts with extensive experience of GA accident investigation coded each accident report independently. The experts had previously been trained together face to face for a week on how to use the HFACS framework. The raters were assigned to analyse two years of the GA accident data to achieve a shared and accurate understanding of the coding process as well as the HFACS framework. The coding process is like this if any causal factor described in the HFACS framework was noted in the examined accident report, it was encoded as '1' and if not noted as '0' To avoid over-representation from any single accident report, each HFACS category was counted at most once. Discrepancies in the categorisation were recorded and discussed until a consensus was reached.
After the raters independently made their initial classifications, inter-rater reliability analysis at the categorical level should be conducted as a consistency check. Cohen's κ coefficient and the simple percentage rate of the agreement are typically utilised in the literature to measure compatibility between coders [27, 37, 38, 56]. The magnitude of the κ coefficient represents the proportion of agreement beyond that expected by chance. According to Landis and Koch [57], for the κ coefficient, we can judge the strength of agreement with the following standards:

κ Statistic	Strength of Agreement
≤ 0	poor
0.01–0.20	slight
0.21–0.40	fair
0.41– 0.60	moderate
0.61–0.80	substantial
and 0.81–1	almost perfect

However, the κ could easily be distorted in some situations, such as where the number of categories is small or where there is a very high agreement between raters related to a large percentage of cases falling into one class [58, 27]. Therefore, the simple percentage rate of agreement (calculated over all paired ratings) was also calculated for inter-rater reliability. For example, in Table 3, in almost all categories, the κ value was over 0.60, indicating substantial agreement. The category of adverse physiological states was an exception. Its κ coefficient was 0.383, although the percent compliance was 96.51% in this category. This is because the frequency of the adverse physiological state category was very low (only 2).

Concerning what level of agreement is acceptable, Li et al. [27] held that it was between 63% and 95%. Li and Harris [37] found reliability figures between 72.3% and 96.4% and described this as acceptable reliability between raters. Shappell and Wiegmann [31] described 85% overall agreement between coders as an excellent level. The rates of compliance obtained in this study were quite high compared to those reported in the literature.

3.3. Relationship Analysis

The HFACS framework permits a relationship analysis between the errors at different levels. χ^2 test of independence, Φ coefficient, and the odds ratio were considered for the evaluation of the relationship between HFACS levels using the database obtained from coding.

3.3.1. χ^2 Test of Independence

It was performed to estimate the statistical strength of the association between the categories in the higher and lower levels of the HFACS framework. It is a common hypothesis test method based on the χ^2 distribution, which is mainly used for classification variables. The χ^2 test has many uses, and the most popular one is to check whether the X and Y variables with two or more classes are interdependent, which is the χ^2 test of independence. The hypothesis tested in this test is 'there is no association' [59]. In this study, the hypothesis is defined as 'there is no association between failures at different HFACS levels.

The χ^2 represents the degree of deviation of the observed value from the theoretical value. The calculation steps were as follows:

$$\chi^2 = \sum \frac{(A-E)^2}{E} = \sum_{i=1}^{k} \frac{(A_i - E_i)^2}{E_i}, \quad i = 1, 2, ..., k. \tag{1}$$

Where A_i =Observed value or frequency of *ith* cell.
E_i =Expected value or frequency of the cell *ith*.
k =The number of cells.

This test has requirements for research data. Specifically, if the number of samples (n) is greater than 40, and the expected cell frequencies are all equal to or greater than 5, researchers should refer to the results of the Pearson χ^2 test. The Pearson χ^2 test is also the original form of the χ^2 test, which was first put forward by the British statistician Karl Pearson in 1990. When any of the expected cell frequencies are between 1 and 5 (n > 40), continuous correction of χ^2 statistics is necessary [59]. Yates' χ^2 test, also called Yates' correction, is used to provide a more conservative result for contingency tables with small cell counts [60]. Yates' correction only replies to 2 × 2 cross tables. For cross tables with any of the expected cell frequencies less than 1, Fisher's exact test provides a better solution. Furthermore, if the number of samples is less than 40, Fisher's exact test is used [59].

3.3.2. Φ Coefficient

The level of the relationship is given by the Φ correlation coefficient. The Φ statistic (varying from 0 to 1, where 1 implies a complete association between two categories, 0 implies that the two categories are independent) is a recommended analysis for two class 2 × 2 tables [36]. In the fourgrid table, the Φ is between 0 and 1, and in other contingency tables, there is no upper limit theoretically. The larger the value, the stronger the correlation degree. The calculation step was as follows:

$$\Phi = \sqrt{\chi^2 / n}. \quad (2)$$

According to Cohen[61], the values of the Φ coefficient can be divided into four sets: the range [0, 0.1) indicates no relationship, range [0.1, 0.3) indicates a low level of relationship, range [0.3, 0.5) indicates a moderate level of relationship, and range [0.5,1] indicates a very high level of association.

3.3.3 Odds Ratio

Finally, the calculation of odds ratios would contribute to an easier understanding of the correlation between HFACS levels [59]. The odds ratio is the ratio of the probability of the presence of an examined variable to the probability of its non-presence with the influence of another variable. If the odds value is greater than 1, then the examined variable is more likely to occur in the presence of another variable. An odds ratio of 1 indicates no association. In this study, the odds ratio provides an estimate of how many times a causal factor at lower operational levels is likely to be observed in the presence of the other causal factor at higher organisational levels. The statistical analyses (reliability analysis and relationship analysis) were conducted using the SPSS (Statistical Package for the Social Science) program (version 22.0).

4. Findings

This part is arranged as follows: first, 109 GA accident reports were analysed descriptively, and then HFACS analysis and relationship analysis results were provided.

4.1. Overall Results

As seen in Table 4, human factors are not limited to pilots or aircrews, but also include air traffic controllers, ground crew, maintenance personnel, passengers, and managers. A total of 81.7% of GA accidents were caused by human factors. This percentage implies that human factors have been the primary cause of GA accidents, followed by environmental and equipment factors. A total of 78.9% of GA accidents were associated with pilots, which is in line with existing research

The three most frequent GA aircraft types in the 109 aircraft accidents were R44II (9.17%), Y5 (6.42%), and R22 (5.50%). This is partly because these three types of aircraft are more often used than other aircraft in the GA operation. Over a quarter of GA accidents involve collisions (26.61%), and LOC (Loss of Control) (20.18%) and CFIT (Controlled Flight into Terrain) (19.27%) are the two most common types of GA accidents besides collisions.

The fatal accident rate was as high as 39%, and 96 people were killed in the GA accidents examined. Cruise or operation is the most critical phase of the flight for GA accidents; 69 (63.3%) accidents occurred in this phase, which relates to the operations involved in the GA accidents (agriculture and forestry-related flights (31.19%) and training flights (31.19%)). Thirteen (11.93%) accidents occurred in the take-off phase of flight, 8 (7.34%) in the landing phase, 7 (6.42%) in the descent phase, 5 (4.59%) in the climb phase, 7 (6.42%) in other phases. According to the Report on Production Safety Accident and Regulations of Investigation and Treatment [62], among the 109 GA accidents, 20 (18.35%) are particularly serious accidents, 8 (7.34%) major accidents, and 81

(74.31%) ordinary accidents.

4.2. HFACS Analysis Results

Since unsafe acts committed by pilots are germane to the examination of GA accident data, we restricted HFACS analysis to 86 pilot-related GA accidents. A total of 532 causal factors were identified in the accident reports. Figure 4 depicts the analysis results for the four HFACS levels. 182 unsafe acts, 201 preconditions for unsafe acts, 142 unsafe supervisions, and 98 organisational influences factors were observed in the GA accidents.

As shown in Figure 5, in level 1, the most prevalent unsafe acts were violations of pilots (66), followed by skill-based errors (63), decision errors (43), and perceptual errors (10). This ranking observed in unsafe acts is similar to another article involving civil aviation accidents that occurred in China [27]. In level 2 preconditions for unsafe acts, physical environment (56) has the highest frequency, followed by mental/physiological limitations (49) and adverse mental states (44). The highest frequency in unsafe supervision level and organisational influences level belongs to inadequate supervision (44) and organisational process (55) causal factors, respectively. Wiegmann and Shappel[34], Li et al.[27], Liu et al. [35], and Filho et al. [26] drew the same conclusion concerning this ranking. The most common HFACS factors observed in the GA accident reports and their corresponding proportions are given in Table 5.

At level 1, the factors most commonly involved were failure to properly prepare for the flight (45%), poor choice (44%), inadequate application of controls (34%), not following the IFR/VFR procedure (34%), breakdown in visual scan (30%) , and failure to see and avoid (17%).

At level 2, for environmental factors, condition of pilots, and personnel factors causal categories, the most frequently observed factors were physical environment (65%), information processing limitation (56%), failed to communicate or coordinate (33%), and pernicious attitude (22%).

For unsafe supervision level, the most common factors were failed to enforce rules and regulations (35%), failed to provide proper or adequate training (29%), failed to provide correct data and other support (21%), and failure to provide oversight (20%). Finally, at level 4 for organisational process, resource management, and organisational climate causal categories, the most frequently cited factor was procedures with 45%. This factor was followed by human resources at 35% and oversight at 31%.

4.3. Relationships between HFACS levels

4.3.1 Relationships Between Adjacent HFACS Levels

For each of the 86 GA accidents, the categorisation of 19 HFACS causal categories was first performed as present (1) or absent (0). Based on the categorisation results, the relationships between the categories were examined individually.

Table 6 shows that there were 12 pairs of significant associations ($p \le 0.05$). There were seven pairs of significant associations between level 4 organisational influences and level 3 unsafe supervision. The resource management category at level 4 was significantly associated with four categories of unsafe supervision: inadequate supervision (χ^2 =26.217, df=1, p≤0.001), planned inappropriate operations (χ^2 =7.055, df=1, p≤0.01), failed to correct a known problem (χ^2 =8.547, df=1, p≤0.01), and supervisory violations (χ^2 =33.214, df=1, p≤0.001). Organisational process was significantly associated with three categories of unsafe supervision: inadequate supervision (χ^2 =19.627, df=1, p≤0.001), planned inappropriate operations (χ^2 =8.524, df=1, p≤0.01), and supervisory violations

(χ^2=32.976, df=1, p≤0.001). Organisational climate was not significantly associated with any level 3 categories.

Three pairs of significant associations existed between the categories at level-3 and level-2. The HFACS level-3 category failed to correct a known problem was significantly associated with the level-2 category technological environment (χ^2=7.495, df=1, p≤0.01). Mental/physiological limitations at level 2 were significantly associated with inadequate supervision (χ^2=4.615, df=1, p≤0.05) and supervisory violations (χ^2=5.503, df=1, p≤0.05) at level 3 respectively.

Two pairs of categories have significant associations between HFACS level 2 preconditions for unsafe acts and level 1 unsafe acts. Mental/physiological limitations were significantly associated with one category of level 1: decision errors (χ^2=10.673, df=1, p≤0.01). Adverse mental states were significantly associated with one category of level 1: violations (χ^2=6.026, df=1, p≤0.05).

The analysis of the level of relationship between categories in HFACS levels is shown in Table 6. In the level 4 categories, the statistically highest significant positive correlation was observed between resource management and supervisory violations in level 3 (Φ=0.621, p≤0.001). There was also a very high correlation between resource management and inadequate supervision (Φ=0.552, p≤0.001), as well as between organisational processes and supervisory violations (Φ=0.619, p≤0.001). In the level 3 categories, there was a moderate correlation between failed to correct a known problem and level 2 category technological environment (Φ=0.335, p≤0.01). At levels 2 and 1, there was a moderate correlation between mental/physiological limitations and decision errors (Φ=0.352, p≤0.001).

Finally, the odds ratios and 95%Cis are given in Table 6. The highest odds ratio was determined between the flawed organisational process and supervisory violations. The occurrence of a poor organisational process (i.e., no official procedures in place) increases the chance of supervisory violations by approximately 62 times. Similarly, when poor organisational processes were present, the odds of inadequate supervision and planned inappropriate operations increased by 9.3 and 4.0 times, respectively. Inadequate supervision was 14 times more likely to be present in the presence of inefficient or poor resource management (i.e., excessive cost-cutting). The odds ratios between resource management and the other three categories in level 3 can be interpreted similarly.

The observed associations would also mean that the probability of adverse technology environment when supervisors failed to correct a known problem (i.e., documents in error, an at-risk aviator) is approximately six times higher. The odds of mental/physiological limitations present increased about three times in the presence of supervisory violations (i.e., failure to enforce rules and regulations) or inadequate supervision (i.e., failure to provide proper training). In turn, decision errors were over four times more likely to occur when there were mental/physiological limitations (i.e., sensory limitation).

4.3.2. Relationships Between Non-Adjacent HFACS Levels

Based on previous research, there are many examples in which organisational failures will directly impact the unsafe acts of pilots, such as violations and decision errors. Dönmez and Uslu[56] analysed the relationships between higher levels in the organisation (unsafe supervision and organisational influences) and level 1 unsafe acts and found that organisational processes and supervisory violations were statistically significant in relation to the violations of the cockpit crew. For this reason, the relationships between HFACS organisational and supervision levels and unsafe acts level were examined in this study, the following Table 7 was obtained.

Level 4 organisational influences versus level 1 unsafe acts found that there were two pairs of significant associations: resource management and decision errors (χ^2=8.31, df=1, p≤0.01), and organisational processes and violations of pilots (χ^2 =5.05, df=1, p≤0.05). Also, there were two pairs of significant associations between level 3 unsafe supervision and level 1 unsafe acts; supervisory violations and violations of pilots (χ^2 =5.292, df=1, p≤0.05), and inadequate supervision and violations of pilots (χ^2 =6.026, df=1, p≤0.05). An intermediate positive correlation was found between level 4 category resource management and decision errors at level 1 (Φ=0.311, p≤0.01). A low positive correlation was found between the other three pairs. The odds ratio analysis results indicate that the presence of management and organisational factors obtained in the analysis of the χ^2 test increased the probability of decision errors and violations of pilots by about 3–4 times.

5. Discussion

5.1 Unsafe Acts

The violations of pilots were the most frequently classified category at Level 1 in the examined GA accident reports. By definition, pilots' violations deviate from safe operating practices, procedures, standards, or rules and often involve fatalities [22]. Failure to properly prepare for flight was the most frequently observed factor in violations. This factor is included in routine violations. Here, the violations of pilots were significantly associated with adverse mental states in level 2, which suggests that adverse mental states such as distraction, loss of situational awareness, and mental fatigue may be the most important precursors of the violations of pilots. The violations made by pilots were nearly four times more likely to occur in the presence of adverse mental states. Measures must be taken to reduce the probability of adverse mental states. The pernicious attitude (i.e., complacency, overconfidence, and poor flight vigilance) was involved in 22% of GA accidents and accounted for one-third of the adverse mental states. Thus, a major focus of training should be to strengthen the safety awareness of GA pilots and increase the relevance of training to GA operation. Krause[63] emphasised that, based on academic research, safety surveys, and accident reports, there were deficiencies in the decision-making ability of pilots during accident flights. The most frequently observed factor in decision errors was poor choice, accounting for approximately 88% of those observed. Poor choice presents an incorrect decision made by pilots among multiple response options. A sound decision is generally based on three basic elements: adequate knowledge, keen perception, and the ability to identify appropriate actions. This would mean that pilots with less experience are more likely to make wrong decisions, especially when faced with time, financial, and other external pressures [64]. By definition, the mental/physiological limitations category at level 2 encompasses issues such as the lack of adequate experience, especially for the complexity of the situation, insufficient reaction time, and information overload. The presence of mental/physiological limitations may be related to decision errors. The empirical study published by Lenné et al. [18] further supports this association. Nonetheless, pilots can regain decision-making ability by developing accurate perceptions and the ability to distinguish between correct and incorrect solutions [63]. Technology (i.e., portable weather data) can also help enhance the decision-making process of pilots [65].

Skill-based errors were the second most frequent category of unsafe acts, whose proportion in GA accidents was very close to the violations. The prevalence of skill-based errors in GA can be explained by the fact that GA pilots often fly less and are offered fewer opportunities for initial and recurrent training sessions than their commercial counterparts [33]. This is the case in China. Adequate flight training and experience could be effective solutions for reducing skill-based errors. The most frequently cited skill-based error for the GA accidents examined was the inadvertent control or handling of aircraft. DoD (Department of Defense)[66] defined this factor as over or under the control of aircraft or systems, which may be associated with a temporary failure of coordination. Perceptual errors had the lowest frequency and were only observed in 10 of the 86 GA accidents. This is due in large part to fewer nondaylight GA operations and great advances in warning devices such as ground collision avoidance systems [26]. Misjudging distance/altitude/airspeed was the most common perceptual error, accounting for 90% of all errors. No statistically significant relationship was found between skill-based and perceptual errors and higher HFACS causal categories.

5.2. Management and Organisational Effect

Decisions by management create flaws within an organisation, which inevitably leads to latent error-producing conditions. These then interact with mental and physical states to generate unsafe acts [22]. Unlike previous research, the high frequencies of organisational and supervision categories observed in the GA accident reports permit the analysis of the relationships between HFACS organisational and operational levels.

5.2.1 Unsafe Supervision

Supervisors are also seen as middle managers at organisations. Causal factors attributed to unsafe supervision failures involved the full range of supervisory factors rather than one category. The factors classified as inadequate supervision (51.16%) and planned inappropriate operations (50%) had the highest percentages within the unsafe supervision category, which parallels the results of other civil aviation accident analyses [22, 27, 33]. The presence of a failure to correct a known problem at unsafe supervision level was associated with the presence of poor technological environment. There was a moderate and significant correlation between the two categories. The failure to correct a known problem category was, in turn, greatly inflated by poor resource management. This was a link between poor technological environment and flawed resource management. Failure to correct a known problem in the HFACS framework refers to situations in which a supervisor fails to correct hazardous acts or unsafe tendencies or fails to initiate remedial actions.

Inadequate supervision and supervisory violations at Level 3 were significantly associated with mental/physiological limitations at Level 2. Physical/mental limitations appeared in more than half of the pilot-related accidents. In China, GA pilots are generally younger than pilots flying aircraft operating under CAAR Part 121 and are much less experienced [67]. Such pilots often fly less sophisticated and reliable aircraft into areas where it is difficult for ATC (Air Traffic Controller) to provide flight support [34]. ATC is regarded as the last line of defence. In addition, GA aircraft have a low flying altitude and a complicated flight environment, resulting in a short response time for pilots. Therefore, GA pilots are more likely to be in situations beyond their training and abilities when flying aircraft. The inadequate supervision category contains issues such as failure to provide adequate technical data or procedures and failure to provide proper and adequate training. Permitting unqualified crew to fly is one of the most common supervisory issues in the category of supervisory violation. Typically, this unsafe supervision behaviour is more likely to occur when there is a shortage of qualified pilots. China has been facing a serious shortage of pilots, which may be the probable reason for the high prevalence of supervisory violations (44.19%). The significant relationship between mental/physiological limitations and the two categories in unsafe supervision level is a clear indication that the GA industry in China has not invested enough in pilot training specifically targeted at improving the emergency response capability of pilots.

The proportion of GA accident reports in which physical environment factor was identified was the highest at level 2. This was related to adverse weather, such as clouds, rain, or thick fog. GA flights are especially vulnerable to adverse weather because of their small aircraft size and low altitude, and pilots tend to complete a flight when facing adverse weather [68]. A small percentage of GA accidents was found to be associated with problems in crew resource management. This is partly because a subset of GA operations is conducted by a single pilot, which reduces the number of communication failures between pilots in the cockpit [34]. In this study, the aircraft in 26 of the 86 GA accidents examined were single-piloted. Adverse mental states were involved in over 50% of GA accident reports. In addition to pernicious attitude (22%), mental fatigue (10%), loss of situational awareness (8%), and channelised attention (8%) were also frequent factors in adverse mental states. Adverse mental states of GA pilots are more likely to have disastrous consequences, as they often fly aircraft alone without reminders from a copilot in the cockpit[26].

5.2.2. Organisational Influences

High-level decisions represent the common starting point for various failure pathways and are the root causes of other failures [22]. Poor resource management was associated with inadequacies in all categories at the unsafe supervision level which in turn affected the preconditions for unsafe acts, and consequently, the actions of pilots. The statistical results suggest that unsafe supervision failures are more likely to be present when there are organisational level issues related to resource mismanagement. Taking supervisory violations as an example, the odds of supervisory violations being present increased by nearly 20 times in the presence of poor resource management. DoD defined poor resource management as a mishap factor negatively affecting system, pilots, and error management, also promoting the emergence of unsafe situations [69]. In the HFACS framework, poor resource management encompasses issues such as the mismanagement of human resources (i.e., inappropriate selection, staffing and training of human resources at an organisational level), monetary resources (i.e., excessive cost cutting), and equipment/facility resources (i.e., purchase of sub-optimal and inadequately designed equipment, failure to remedy known design flaws in existing equipment). Among them, poor human resource management issues appear more frequently in GA accidents. In addition, GA companies in China do not have procedures that address contingencies. As such, managers often fail to identify problems until an accident occurs.

Organisational process showed strong relationships with three supervisory categories: inadequate supervision, planned inappropriate operations, and supervisory violations. The occurrence of problems in the organisational process increased the probability of unsafe supervisory practices. According to DoD, deficiencies in organisational processes will result in inadequacies in individual, supervisory, and organisational performance and cause unidentified hazards and uncontrolled risk, resulting in human error or an unsafe situation [66]. In the HFACS framework, deficiencies in organisational process include such issues as operations (i.e., undue time pressure, high workload, poor incentive system), procedures (failure to set clearly defined objectives, no official procedures in place, lack of work instructions), and oversight (inappropriate hazard recognition, poor risk management programs, lack of pilot programs) [29].

5.2.3 Unsafe Supervision and Organisational Influences

When examining the relationships between supervision and organisational levels and unsafe acts level, very important findings were obtained. Organisational processes, inadequate supervision, and supervisory violations were found to be statistically significant with violations of pilots.

The DoD emphasised that poor organisational processes will negatively influence the performance of pilots, as well as supervisory and organisational practices[66]. Organisational processes fall into three categories: operations, procedures, and oversight. The operations included in the organisational process are also defined as the working conditions provided to workers by upper-level management, including operational tempo, time stress, and schedules. For example, in China, the increased demand for crop dusting between May and August each year leads the crew to fly a very demanding schedule arranged by management. As a result, more unsafe acts of pilots and a high accident rate were observed during this period [2]. Procedures in the organisational process refer to official methods (which involved standards, documentation, and instructions) on how to do the job. The oversight factor is the continuous monitoring of other organisational factors, such as resources, organisational processes, and organisational climate, for a safe operating environment. Therefore, not surprisingly, the deficiencies in these factors are related to violations committed by pilots.

Inadequate supervision is described as a supervisory failure to identify hazards, control risks, and provide training and oversight [66]. For instance, supervisors fail to track the qualification or performance of pilots, and therefore are unable to identify risky pilots who are more likely to violate rules or regulations [29]. Supervisory violations are a wilful disregard for rules and regulations by managers, such as the failure to enforce rules and regulations, authorising unnecessary hazards, and permission to allow a pilot to fly without the necessary qualification. Maurino et al. [22] argued that poor supervisory examples were generally associated with violations of pilots. When violations at management levels become more common**,** pilots would likely regard some nonconformist flying acts as accepted and hence ignore flight rules. This may even trigger a lack of awareness that they are in fact violations and not the norm [31]. It is widely recognised that addressing the unsafe behaviour of 'violations' is more complex and difficult. The associations obtained in this study indicate that violations of pilots require organisational remedies.

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6. Conclusion

HFACS framework was used to classify the casual factors from GA accident investigation reports. With the data on GA accident factor information, we conducted a statistical analysis of the associations between categories at different levels. According to the analysis results, violations, skill-based errors, and decision-based errors were the most frequently reported unsafe acts of GA pilots, while poor resource management and inefficient organisational processes were found to be the root causes of these unsafe acts. Besides, the relationship between violations and organisational and management factors was statistically revealed.

The effect of organisational factors on unsafe acts of GA pilots received less attention from researchers compared with the relationship between organisational factors and unsafe acts of airline pilots, which is not conducive to GA enterprises accident prevention. GA enterprises are the main body of GA aircraft operators in countries whose GA factor market is relatively backward (e.g., China) or geographical location is special (e.g., Japan). Many critical flight missions needed to be carried out by GA enterprises for efficiency and safety reasons, like emergency rescue, air medical, and flight training. In China, over 90% of GA flight hours are produced by GA enterprises. The research findings on the causal factors of GA accidents and the key associations between management and organisational factors and unsafe acts will provide valuable guidance for GA enterprises to determine the effective combination of safety interventions. Interventions at unsafe acts are unlikely to have expected impact on safety unless effective supervision, organisational processes and resource management are in place to provide support. Besides, knowing the most common error forms and the pattern of GA accident path can help regulators develop targeted intervention measures and objectively evaluate system safety programs.

Finally, it is important to recognize the limitations of our study. We use GA accident reports provided by CAAC to classify causal factors, not the primary data. There is a difference between "What's the causes of GA accidents?" and " What causes do investigation experts think caused GA accidents?". In China, aviation accident investigation is conducted by CAAC. They might choose not to disclose or play down some causal factors to avoid being too incriminating. As a result, these GA accident reports may suffer bias[26]. The future GA accident investigation can consider the use of HFACS framework or other human error analysis models to guide the collection of data. Besides, scholars have put forward that some emerging organisational factors like learning from experience and change management may not be well identified by HFACS model[25]. However, these factors were rarely observed in the GA accident reports studied, most of the organisational factors included in these GA accident reports can be well identified by HFACS. Future work could focus on the emerging organisational factors identification problem of human error analysis models to help contribute to extensive research on organisational factors.

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Figure 1. GA and scheduled air transport accidents statistics in China from 1950 to 2019 for every 5 years

Note: GA=general aviation.

Figure 2. Comparison of direct causes of civil aviation accidents in China between 1975 and 2015（%）

Note: The full colour version of this figure is available online.

Figure 3. HFACS framework

Note: HFACS= human factors analysis and classification system.

Figure 4. Frequency of HFACS levels

Note: HFACS= human factors analysis and classification system.

Figure 5. Frequency of HFACS causal categories.

Note: HFACS= human factors analysis and classification system.

Table 1

Applications of HFACS framework.

Types of accidents	Countries involved	Studies
Commercial aviation accidents	Australia, China, The United States, India	(Ting and Dai [32]), (li et al. [27]), (Shappell et al. [33]), (Wiegmann and Shappell [34]), (Gaur [24])
GA accidents	German, Brazil, Australia, the United States, China	(Dambier and Hinkelbein [16]), (Filho et al. [26]), (Lenné et al.[18]), (Wiegmann et al.[13]), (Liu et al.[35])
Military aviation accidents	the United States, China	(Shappell and Wiegmann [36]), (Li and Harris [37]), (Li and Harris [38])
Railway accidents	China, Australia, the United States	(Zhan et al. [39]), (Baysari et al. [40]), (Baysari et al. [41])
Maritime accidents	South Korea, Germany, Australia, China, Sweden, Canada, New Zealand, UK, Denmark	(Wang et al. [42]), (Celik and Cebi [43]), (Schröder-Hinrichs et al. [44]), (Akyuz and Celik[45])
Maintenance-related accidents	Australia, Canada, New Zealand, UK, the United States	(Rashid et al. [46]), (Schmidt et al. [47]), (Rashid [48])
Heath and Medicine	the United States	(Diller et al.[49]), (Cohen et al.[50])
Construction accidents	China	(Chen[51])
Chemical storage accidents	China	(Jiang et al.[52])
Refinery accidents	the United States	(Theophilus et al.[53])
Mining accidents	Australia	(Patterson and Shappell [54])

Note1: HFACS= human factors analysis and classification system.

Note2: GA=general aviation.

Table 2

Levels of HFACS framework with descriptions.

No.	Levels	Descriptions
1	Unsafe acts (Active failures)	Errors or violations committed by those at the sharp end of the system
2	Preconditions for unsafe acts (Latent failures)	Make up the underlying causes of accidents and are by-product of latent organisational failures
3	Unsafe supervision (Latent failures)	Contains most of the hidden errors and derives from decisions taken in the managerial sphere
4	Organisational influences (Latent failures)	The highest level of failure in HFACS lying dormant in the system and are directly associated with supervisory practice

Note: HFACS= human factors analysis and classification system.

Table 3

Inter-rater reliability tests results.

HFACS category	Cohen's κ	Percentage agreement (%)
Level 4		
Resource management	.927	96.51
Organisational climate	.774	95.35
Organisational process	.950	97.67
Level 3		
Inadequate supervision	.814	90.70
Planned inappropriate operations	.814	90.70
Failed to correct a known problem	.793	94.19
Supervisory violations	.924	96.51
Level 2		
Physical environment	.975	98.84
Technological environment	.937	97.67
Adverse mental states	.953	97.67
Adverse physiological states	.383	96.51
Mental/physiological limitations	.844	93.02
Crew resource management	.878	94.19
Personal readiness	.882	94.19
Level 1		
Decision errors	.884	94.19
Skilled-based errors	.907	96.51
Perceptual errors	.750	94.19
Violations	.935	97.67

Note: HFACS= human factors analysis and classification system.

Table 4

Main causes of GA accidents

The factors that caused the accidents	Frequency (n)	Percent (%)
Pilots/Aircrew	86	78.9
Air traffic controller	2	1.8
Ground crew	8	7.3
Maintenance personnel	5	4.6
Passengers	2	1.8
Managers	22	20.2
Total human factors	89	81.7
Environmental impacts	42	38.5
Equipment, materials	21	19.3

Note1: GA=general aviation.

Note2: Since multiple factors may be observed in each GA accident report at the same time, it cannot be expected that the sum of the percentages is equal to 100%.

Table 5

Most common causal factors.

HFACS Levels	Most common causal factors	Percentage (%)
Unsafe acts	Failed to properly prepare for the flight	45
	Poor choice	44
	Inadequate application of controls	34
	Not follow IFR/VFR procedure	34
	Breakdown in visual scan	30
	Failure to see and avoid	17
	Misjudged distance/altitude/airspeed	13
	Not current/qualified for the mission	13
	Uneven distribution of attention	12
	Minimum descent altitude not maintained	12
Preconditions for Unsafe acts	Physical environment	65
	Information processing limitation	56
	Failed to communicate or coordinate	33
	Personality traits and pernicious attitude	22
	Technological environment	16
	Mental fatigue	10
Unsafe Supervision	Failed to enforce rules and regulations	35
	Failed to provide proper/adequate training	29
	Failed to provide correct data or other support	21
	Failed to provide oversight	20
	Improper manning	15
	Authorized unqualified crew/aircraft for flight	14
	Failed to track qualification/performance	12
	failed to provide adequate brief time/preparation	10
Organisational Influences	Procedures (standards/clearly defined objectives/documentation/instructions)	45
	Human resources (selection/staffing/training/maintaining)	35
	Oversight (risk management/safety programs)	31
	Equipment resources (poor design/purchasing of unsuitable equipment)	9
	Structure (chain of command/communication/formal accountability for actions)	8
	Operations (operational tempo/time stress/schedules/production quotas)	7

Note1: HFACS= human factors analysis and classification system.

Note2: Because each general aviation accident is generally caused by a variety of causal factors across several HFACS categories, the percentages in the table do not add up to 100%.

Table 6

Relationship analysis results- adjacent HFACS levels

HFACS Levels	χ^2 Test		Φ Coefficient		Odds Ratio	95% CI
	χ^2	p	Φ	p		
Level 4-Level 3						
Resource Management x Inadequate Supervision	26.217	0.000***	0.552	0.000***	14.307	[4.655, 43.971]
Resource Management x Planned Inappropriate Operations	7.055	0.008**	0.285	0.008**	3.345	[1.346, 8.312]
Resource Management x Failed to Correct a Known Problem	8.547	0.003**	0.315	0.003**	5.127	[1.608,16.350]
Resource Management x Supervisory Violations	33.214	0.000***	0.621	0.000***	19.600	[6.399, 60.035]
Organisational Process x Inadequate Supervision	19.627	0.000***	0.478	0.000***	9.314	[3.231, 26.849]
Organisational Process x Planned Inappropriate Operations	8.524	0.004**	0.315	0.004**	3.958	[1.535, 10.206]
Organisational Process x Supervisory Violations	32.976	0.000***	0.619	0.000***	61.667	[7.778, 488.915]
Level 3-Level 2						
Failed to Correct a Known Problem x Technological Environment	7.495	0.006**	0.335	0.002**	6.200	[1.790, 21.477]
Inadequate Supervision x Mental/Physiological Limitations	4.615	0.032*	0.232	0.032*	2.594	[1.078, 6.244]
Supervisory Violations x Mental/Physiological Limitations	5.503	0.019*	0.253	0.019*	2.901	[1.177, 7.150]]
Level 2-Level 1						

Mental/Physiological Limitations x Decision Errors	10.673	0.001***	0.352	0.001***	4.449	[1.776,11.144]
Adverse Mental States **x** Violations	6.026	0.014*	0.265	0.014*	3.900	[1.259,12.081]

* p ≤0.05 **p ≤0.01 ***p≤ 0.001.

Note1: HFACS= human factors analysis and classification system.

Note 2: Degrees of freedom=1 for the entire table.

Note 3: All other comparisons were non-significant.

Table 7

Relationship analysis results-non adjacent HFACS levels

HFACS Levels	χ^2 Test		Φ Coefficient		Odds Ratio	95% CI
	χ^2	p	Φ	p		
Level 4-Level 1						
Organisational Process x Violations	5.05	0.025*	0.242	0.025*	3.231	[1.130,9.237]
Level 3-Level 1						
Supervisory Violations x Violations	5.292	0.021*	0.248	0.021*	3.864	[1.161,12.859]
Inadequate Supervision x Violations	6.026	0.014*	0.265	0.014*	3.900	[1.259,12.081]

* p ≤0.05 **p ≤0.01 ***p≤ 0.001.

Note: HFACS= human factors analysis and classification system.