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The Human Factor in Aviation: Psychological and Physiological Aspects of Working in High-Altitude Airports

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Abstract

This article examines the human factor in aviation, focusing on the psychological and physiological aspects of working in high-altitude airports, using Tribhuvan International Airport as a case study. The relevance of the topic stems from increased risks associated with hypoxia, unstable weather conditions, and limited maneuvering space, all of which demand a high level of preparedness and adaptability from aviation personnel. The novelty of the study lies in combining data on physiological changes experienced by pilots and air traffic controllers under high-altitude conditions with psychological strategies aimed at maintaining performance in extreme environments. The paper outlines the specific stressors characteristic of mountainous airfields, explores mechanisms for stress management, and highlights methods for preventing human error. Particular attention is given to identifying current risks and reviewing existing practices designed to enhance overall safety. To achieve these objectives, the study employed comparative and content analysis of scientific sources, along with generalization and synthesis of the collected data. The conclusions presented offer insights for aviation professionals seeking to better understand the interplay of physiological and psychological factors in high-altitude conditions. This article is intended to be of value to researchers, airline managers, and aviation training centers.

Keywords: *Human Factor, Aviation Psychology, High-Altitude Airports, Physiological Stress, Fatigue and Stress, Flight Safety, Organizational Factors, Hypoxia, Cognitive Functions, Crew Performance.*

INTRODUCTION

The demanding conditions of high-altitude airports impose specific requirements on aviation personnel, as reduced atmospheric pressure, sudden weather changes, and limited room for maneuver introduce additional risks to flight safety.

The relevance of this topic lies in the fact that human error and occupational burnout under such conditions can lead to incidents that negatively impact the entire aviation safety system. Psychological and physiological aspects of the work performed by pilots, air traffic controllers, and cabin crew in mountainous environments become key factors influencing reaction speed, decision-making, and the overall quality of flight management.

The aim of this article is to analyze the influence of the human factor on the performance of aviation personnel in high-altitude airports, taking into account various physiological and psychological characteristics.

To achieve this goal, the following three objectives were set:

1. To identify the main physiological factors associated with hypoxia, physical strain, and noise exposure typical of mountainous aerodromes;
2. To analyze psychological aspects such as stress, burnout, and cognitive load during professional tasks;
3. To summarize existing practices aimed at maintaining a high level of safety in high-altitude conditions and reducing the risk of human error.

The novelty of this study lies in the combined consideration of both medical-physiological and psychological aspects of aviation labor within a single framework, enabling a comprehensive assessment of risks and identification of the interrelations between various factors that influence flight performance and safety.

MATERIALS AND METHODS

This study draws on research focused on the impact of the human factor on safety and operational efficiency in the challenging environment of high-altitude airports.

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I.O. Bajgai and K.L. Shrestha [1] examined the ecological conditions and the influence of external factors—particularly air quality—on airport operations in mountainous terrain, emphasizing the indirect effects on the health and productivity of aviation personnel.

E. Balta, A. Psarrakis, and A. Vatakis [2] highlighted increased cognitive load among air traffic controllers and explored the link between psychological strain and time perception, which is especially critical when coordinating flights in mountainous areas.

A. Bhattarai, S. Dhakal, Y. Gautam, and N. Bhattrai [3] focused on safety culture in aviation, showing how organizational factors shape personnel behavior in complex topographic conditions.

M. Bhattarai and B. Sapkota [4] investigated noise exposure levels around Tribhuvan International Airport, identifying risks related to acoustic stress and fatigue among flight crews.

C.G. Gemmano, M.L. Giancaspro, S. Galiotto, and A. Manuti [5] emphasized the importance of continuous training and burnout prevention among aviation professionals, especially under elevated psychophysiological demands on flight crews.

J. Kim, M. Yu, and S.S. Hyun [6] addressed the root causes of human error linked to stress and fatigue, demonstrating how measures to reduce overload and optimize scheduling can enhance flight quality and safety.

I. Koglbauer and S. Biede [7] described modern tools and methods in aviation psychology for assessing cognitive and emotional aspects of crew performance under high-pressure conditions.

E.C. Marqueze, E.A. de Sá e Benevides, A.C. Russo, M.S.G. Fürst, R.C. Roscani, P.C.V. Guimarães, and C.A. Salim [8] analyzed organizational health risks for aviators, such as night shifts and extended duty hours, which further increase stress in high-altitude environments.

K. Mishra [9], within the framework of industrial and organizational psychology, examined decision-making under high workloads and emphasized the importance of behavioral competence among flight crews in preventing error.

R.K. Phuyal and N. Joshi [10] investigated passenger satisfaction with services at Tribhuvan Airport and demonstrated a connection between staff performance and perceived safety in the complex context of mountainous operations.

Probing for Probe's Sake: Aircraft Accident Investigations in Nepal (NIMJN) [11] provided an overview of aviation accident investigation practices in Nepal, critically assessing the effectiveness of existing commissions, and highlighting the formalistic nature of current procedures, lack of institutional reform, and prevalence of superficial conclusions that do not lead to tangible safety improvements.

G. Regmi, S. Shrestha, S. Maharjan, and A.K. Khadka [12] analyzed the weather conditions preceding the crash of US-Bangla flight at Tribhuvan International Airport, identifying meteorological factors that contributed to the incident. The authors stress the need for careful consideration of rapidly changing and complex weather patterns in mountainous regions to prevent similar events in the future.

A combination of scientific research methods was used in preparing this article:

1. A comparative method was applied to juxtapose findings from studies on the human factor in aviation and to identify common trends related to psychological and physiological stress experienced by personnel in high-altitude airports.
2. Historical and legal analysis (in examining the evolution of safety approaches and human factor considerations) was combined with content analysis of academic sources, enabling the systematization of key problems and proposed solutions.
3. Finally, generalization and synthesis of the collected data allowed for the development of a comprehensive understanding of the interaction between organizational, psychological, and physiological factors affecting the performance and health of aviation personnel in high-altitude environments.

RESULTS

The human factor is one of the key components in ensuring aviation safety and operational efficiency at high-altitude airports, where challenging geographical conditions, unstable weather, and limited maneuvering space introduce additional risks [9]. The interplay between psychological and physiological aspects of aviation personnel's activities in such environments becomes critically important for preventing errors, enhancing situational awareness, and maintaining the necessary level of performance [7].

The focus area for the analysis of the human factor and its associated psychological and physiological characteristics in high-altitude aerodrome operations was Tribhuvan International Airport (TIA), located in the Kathmandu Valley. TIA lies 5.56 kilometers east of Kathmandu (see Figure 1) and sits at the intersection of three districts: Kathmandu, Bhaktapur, and Lalitpur. Its coordinates are 27°51′49.72″ N, 85°21′28.52″ E, and it is situated at an elevation of 1,338 meters above sea level, already presenting specific conditions for takeoff and landing operations. The total runway length is 3,350 meters [1].

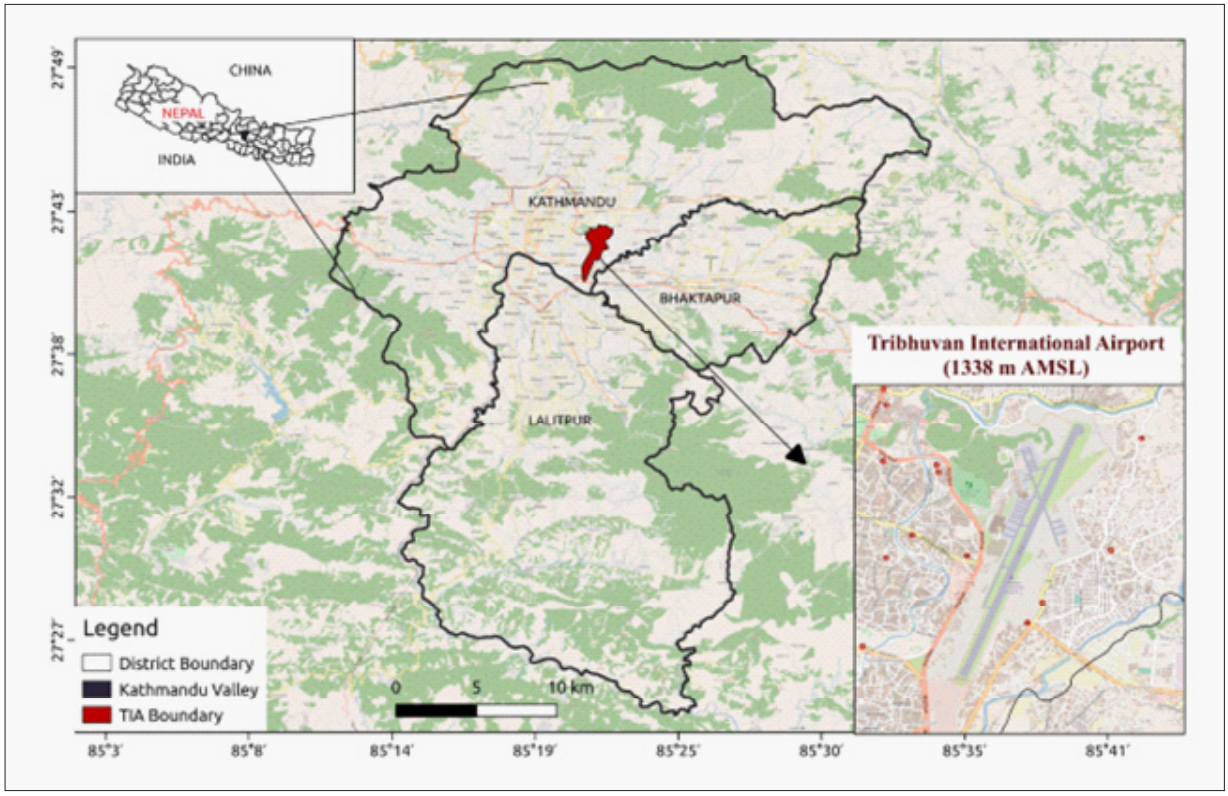

Figure 1. Map of the study area [1]

TIA serves both international and domestic flights and is the busiest airport in Nepal in terms of passenger and flight volume. It operates one terminal for domestic and one for international flights. TIA functions as a hub for several Nepali airlines and over 30 international carriers, connecting the country with destinations across Asia and the Middle East. In 2018, the airport handled 4.34 million international passengers, an 11.70% increase over 2017. According to forecasts by the Asian Development Bank, international passenger traffic at TIA will reach 7.29 million by 2028 and 9.92 million by 2035 (CAAN, 2020). Given the mountainous terrain and high traffic volume, the operational conditions at TIA can significantly affect the psychophysiological state of flight crews and ground personnel, highlighting the importance of analyzing the human factor in flight operations [1].

At high-altitude airports such as Tribhuvan International, pilots, air traffic controllers, and cabin crew face a range of factors that increase physiological and psychological strain [3]. Among the physiological factors, particular attention is given to the impact of reduced atmospheric pressure and the risk of hypoxia. Oxygen deficiency can impair cognitive functions, slow reaction times, and increase the likelihood of human error [2]. Additionally, low pressure and insufficient oxygen can accelerate fatigue and worsen exhaustion, especially during night shifts or extended duty periods with limited opportunities for rest [8].

Psychological factors, stemming from high-stress situations and the heavy responsibility of decision-making in complex terrain, further intensify the negative effects of physiological stressors [5]. The operational environment, marked by potential hazards during approach and takeoff in mountainous zones, requires constant focus from the crew. At the same time, emotional tension accumulates due to the responsibility for passenger safety and the necessity of responding swiftly to external changes [6].

Communication requirements in the cockpit and with ground services become significantly more demanding in high-altitude airport operations, as complex terrain necessitates stricter adherence to procedures and meticulous coordination among all flight participants [4]. The workload on air traffic controllers in such conditions also increases due to the need to account for sudden weather changes, high traffic density, and limited maneuvering space for aircraft [2]. Psychologically, this operational mode leads to elevated stress levels and requires close monitoring of personnel well-being, including early detection of signs of emotional burnout [5].

From an organizational standpoint, optimizing schedules and reducing excessive workloads become essential to ensure that staff have sufficient time for recovery and rest [8]. Systematic monitoring of performance and psychophysiological indicators, alongside the implementation of psychological support programs, helps reduce the risk of human error [6]. Additionally, informational campaigns aimed at fostering a safety culture and preventing burnout contribute to

enhancing collective responsibility and promoting a positive attitude toward compliance with strict operational protocols [3].

From an environmental perspective, the nature of high-altitude airports—such as Tribhuvan in Kathmandu—imposes additional constraints on infrastructure, often resulting in elevated noise levels from air traffic. This creates added strain on the auditory and vestibular systems of crew members [4]. Constant acoustic stress may intensify fatigue and reduce attentiveness, which underscores the need for mitigation measures such as scheduled breaks and the use of personal protective equipment [9]. At the same time, conditions must be maintained to ensure that passengers feel safe and receive quality services, as customer satisfaction is closely linked to the organization and effectiveness of airport operations [10].

In assessing the impact of high-altitude conditions on the human body and aviation personnel performance, several studies emphasize the need to identify specific physiological factors that most critically affect work capacity and flight safety [2; 4; 8]. These are summarized in Table 1, which outlines the main physiological aspects characteristic of high-altitude airports and their potential effects on crew and ground staff.

Table 1. Key physiological factors in high-altitude airport environments (source: compiled by the author based on [2; 4; 8])

Factor	Brief Description	Potential Consequences
Hypoxia	Inadequate oxygen saturation due to reduced atmospheric pressure	Slower reaction times, cognitive impairment, increased fatigue
Low atmospheric pressure	Decreased partial pressure of oxygen, increasing cardiovascular strain	Dizziness, impaired motor coordination, higher risk of operational errors
Elevated noise levels	Airport areas in mountainous terrain experience intensified noise from aircraft	Constant acoustic stress, potential reduction in alertness, increased irritability
Physical overexertion	Intense shifts and prolonged duty cycles combined with insufficient rest	Decline in physical well-being, risk of somatic disorders, decreased vigilance

In addition to physiological limitations, psychological and organizational factors directly tied to the human factor play a critical role in high-altitude airport operations. Table 2 below summarizes key stressors and recommended measures for minimizing the risk of errors and improving performance under challenging conditions [5; 6; 7].

Table 2. Psychological and organizational factors in aviation personnel performance at high-altitude aerodromes (source: compiled by the author based on [5; 6; 7])

Factor	Manifestations and Stressors	Recommended Measures
High cognitive load	Decision-making under restricted maneuverability and rapidly changing conditions	Situational awareness training, critical scenario drills, use of flight simulators
Psychological stress	Responsibility for passenger safety, anxiety due to terrain or weather	Mental health support (counseling, coaching), clear protocols for crew-ATC communication
Emotional burnout	Accumulated fatigue and negative emotions due to sustained high-intensity work	Proper shift planning and rest periods, early burnout detection, task rotation
Organizational factors	Uncoordinated schedules, lack of flexibility in handling unexpected events	Load monitoring systems, adaptive timetables, regular procedural and coordination reviews

Together, these two tables illustrate which physiological and psychological/organizational factors most significantly affect the performance of flight and ground crews at high-altitude airports. Presenting the data in this format helps structure the information for further discussion and adjustment of managerial or training strategies.

The results of the conducted analysis confirm the significant impact of the human factor on flight safety in high-altitude airport operations. In Nepal, where most aerodromes are located in mountainous terrain, human error and related factors were identified as either the primary or a contributing cause in nearly all of the 109 documented aviation incidents [11]. Flight safety at the country's main international hub—Tribhuvan International Airport in Kathmandu—also remains a concern: since the airport's opening, 13 takeoff or landing accidents have been recorded, resulting in a total of 392 fatalities. Notably, many of these incidents occurred under complex external conditions. For example, the crash of flight BS211 (Bombardier Q400) at Tribhuvan in March 2018 took place amid rapidly changing weather conditions: at the time of the accident, two powerful mountain winds converged over the valley, generating severe turbulence and wind shear over the airfield [12]. The unexpected impact of these factors made aircraft control more difficult and likely disoriented the crew, contributing to the crash. This case illustrates the link between extreme high-altitude conditions and the human factor in determining flight outcomes.

Psychological and physiological stressors in mountainous

environments act as additional triggers for aviation incidents. The thin atmosphere at high altitudes affects pilot physiology, with reduced partial oxygen pressure capable of causing hypoxia, which subtly impairs cognitive functions. Experimental studies show that even moderate hypoxia (oxygen saturation <90% at ~4,000 meters) nearly doubles the frequency of procedural errors among pilots compared to normoxic conditions. Simultaneously, both pilots and air traffic controllers operate under heightened psychological pressure due to the challenging terrain and meteorological hazards. Various stressors—including adverse weather, emotional state, and psychosocial factors—can hinder the crew's ability to effectively apply their skills and resources during flight. When layered onto the physiological strain of high altitude, this psychological pressure increases the likelihood of human error during critical flight phases such as takeoff and landing at high-altitude aerodromes [11].

The findings highlight the need for a comprehensive strategy to prevent such incidents in the future. A key measure is improving pilot training for operations in mountainous and high-altitude environments. In particular, greater emphasis is needed on crew resource management (CRM) training and its effective implementation in practice. The CRM concept focuses on the optimal use of all available resources—crew, equipment, and information—to enhance situational awareness and reduce the impact of the human factor, a principle supported by global experience with CRM integration [11]. However, training alone is not sufficient; continuous oversight and support of flight crews are required, especially in light of the additional stressors pilots face in mountainous conditions.

In addition to addressing the human factor, technological and organizational improvements are also crucial. The implementation of advanced systems for terrain and turbulence warnings, as well as the use of high-precision meteorological forecasting for mountainous regions, is strongly recommended. For instance, atmospheric modeling (WRF) in a 2020 study demonstrated the ability to forecast mountain winds and turbulence similar to those that preceded the 2018 Tribhuvan crash. This capability could provide crews with early warnings of potentially hazardous conditions. The integration of these measures—including improved personnel training and selection, consideration of psychophysiological limitations, deployment of advanced technologies, and strict adherence to procedures—is essential to minimizing the influence of the human factor and ensuring safer operations at high-altitude airports in the future [12].

In conclusion, the human factor in aviation is clearly manifested in high-altitude airport operations, affecting both the physiological and psychological dimensions of personnel performance. Low atmospheric pressure and the associated risk of hypoxia negatively impact cognitive functions and reaction times, while constant psychological stress caused by complex terrain and the responsibility for passenger safety can lead to chronic stress and emotional burnout [7]. Adjustments to work schedules, the introduction of effective training and psychological support programs, and the use of personnel condition monitoring tools help mitigate these negative effects and enhance overall operational efficiency in high-altitude airport environments [8].

DISCUSSION

The results obtained from the analysis of sources confirm the critical role of psychological and physiological factors in shaping the level of safety and operational efficiency in high-altitude airport environments. The identified physiological aspects—such as the risk of hypoxia and increased noise exposure [1; 4]—align with findings that suggest human performance and reaction speed may significantly decline under conditions of oxygen deficiency or prolonged acoustic stress [9]. At the same time, the importance of psychological components has also been highlighted, particularly the cumulative effects of stress, burnout, and elevated cognitive load, which are especially pronounced in situations involving limited maneuverability and rapidly changing weather conditions [2; 6].

The review indicates that regular assessment of personnel's psychophysiological condition, combined with the implementation of preventive measures, contributes to reducing risks associated with the human factor [5]. However, studies emphasize that the effectiveness of such an approach is achieved only when organizational aspects are considered, including proper shift planning and the deployment of monitoring systems to track workload and fatigue levels [7; 8]. Similar conclusions regarding the importance of internal coordination within organizational structures are found in studies focused on aviation safety culture: collective engagement and mutual support among staff help create an environment that minimizes the potential for error [3].

Analysis of the literature [6; 10] further shows that improvements in professionalism and employee satisfaction under the challenging conditions of mountain aerodromes have a direct impact on passengers' perception of safety and the quality of services provided. Special attention should be given to the periodic updating of pilot and controller competencies, as the fast-changing conditions in mountainous terrain require flexible cognitive skills and the ability to act under time pressure [8]. Systematic training programs, including situational awareness workshops and specialized simulation exercises, have proven effective in reducing stress levels and improving decision-making quality [7].

Thus, the collective findings from existing research suggest that a comprehensive understanding of the human factor in high-altitude conditions requires not only medical and physiological analysis but also consideration of organizational and psychological dimensions. The introduction of preventive strategies aimed at preserving the psychophysiological well-

being of crews may prove to be a decisive factor in reducing the number of incidents and errors attributable to human factors [5]. At the same time, the effectiveness of such measures largely depends on the management approach and the systemic support provided by aviation organizations, which must ensure access to training resources and foster a supportive environment for information exchange and mutual assistance.

CONCLUSION

This study confirmed that the combined effects of physiological and psychological stressors at high-altitude airfields create a unique risk profile that can significantly reduce the cognitive resources and reaction speed of aviation personnel. The combination of hypoxic load, atmospheric pressure fluctuations, acoustic stress and physical fatigue is aggravated by the emotional stress caused by the need to make decisions in conditions of limited maneuvering space and unstable meteorological conditions. Without timely diagnosis of this complex stress and flexible adaptation of work schedules, the likelihood of errors increases many times over. Preventive medical programs with regular monitoring of blood oxygen saturation, cardiorespiratory and neurovegetative parameters, as well as "oxygen pauses" for crews and dispatchers can reduce the negative impact of low partial pressure of oxygen. Advanced crew resource management training, supplemented by mountain airfield and sudden wind shear scenarios, enhances situational awareness, while the integration of high-fidelity weather models and 3D terrain maps into onboard and control room systems improves the quality of operational decisions.

It should be emphasized that the effectiveness of these measures is directly related to the state of the corporate culture. Open feedback, the rejection of a punitive approach to incident analysis, and the constant exchange of experience between flight, dispatch, and technical personnel create an environment in which the risk of human error is minimized naturally. Fatigue management systems based on automated recording of wakefulness hours and personalized schedules create an additional protective barrier. However, the results of the study are limited geographically: most sources describe the specific conditions of Tribhuvan Airport and other sites in Nepal. Longitudinal studies covering several seasons are needed, as well as unification of stress and cognitive function assessment methods to improve data comparability.

Further research should be focused on developing bioinformatic models that predict the likelihood of cognitive errors based on comprehensive monitoring of physiological parameters, as well as on experimental testing of protocols for corrective oxygenation and hypoxic training. Comparison of the impact of organizational culture on personnel resistance to stress in different mountain regions and analysis of the degree of automation of work processes will provide a deeper understanding of how the cognitive load is redistributed and what mechanisms can lead to skill degradation. Ultimately, successful reduction of the human factor influence is possible only with the integration of medical and physiological support, psychological stability and organizational adaptability, which requires close interaction between specialists in aviation medicine, psychology, ergonomics, meteorology and engineering. The implementation of the described measures will not only increase flight safety, but also improve the socio-economic indicators of high-altitude airports - reduce the cost of delays, reduce staff turnover and strengthen the reputational attractiveness for international carriers, ensuring sustainable development of aviation in mountain regions.

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