HSI2024 Human Systems Integration Conference
Jeju, Korea
August 27-29, 2024

Study on Structure Model of Stressors for Pilot Cadets in Flight Training Based on DEMATEL-ISM

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Abstract. Establishing a structural model of stressors for pilot cadets in flight training, this study developed a scale through interviews and literature research. Using the SHEL model for dimensional analysis, 18 stressors across five dimensions were identified. These stressors were evaluated through dimensional analysis and expert scoring, and modeled using DEMATEL and ISM. The model calculated the influencing, influenced, center, and cause degrees of each stressor and established a hierarchical interpretative structure. Key underlying stressors identified include weather conditions and unsafe incidents. Stressors like psychological pressure, difficulty, and progress in flight training were significantly impacted by other factors. Notably, psychological pressure, training difficulty and progress, and instructor relationships were found to be most influential on cadets' stress. The DEMATEL-ISM method effectively established a structured hierarchical model of stressors in cadet flight training. The findings suggest that flight training schools should enhance safety management and instructors should positively influence cadets to manage stress effectively.

Introduction

Pilot human error has been considered as a primary cause of aviation accidents[1,2]. Data from the Civil Aviation Administration indicates that pilot errors contribute to about 70% of aviation accidents. This statistic is further supported by figures from the National Transportation Safety Board (NTSB), which reveal that pilot human error accounted for about 27% of accidents operating under Part 121 of Federal Aviation Regulation(FAR) and 70% of accidents operating under Part 135 [3,4]. These findings underscore the critical link between pilot performance during training and their behavior in actual flights. It's crucial to note that various investigation reports on aviation accidents identify instances of non-standard operational behavior or abnormal psychological states in pilots that are evident during actual flight incidents. Importantly, these behaviors and states often have corresponding symptoms that were detectable during the training[5,6]. This correlation suggests that early detection and intervention during training could be key in preventing such behaviors from translating into actual flight risks.

As consequence, it's pertinent to consider the factors influencing pilot stress responses during flight training. Krahenbuhl GS's research highlights the impact flight instructors can have on pilot tension within simulator environments, reveals that instructors with negative attitudes can exacerbate pilot tension, underscoring the role of instructor demeanor in pilot stress management[7]. Shi Xiaojing conducted a detailed study using questionnaires to examine stressors encountered by civil aviation pilots during their training, which provides an in-depth exploration of the various stress-inducing elements in pilot training environments[8]. In investigating the workplace stressors among ab-initio pilots, B. Kilic et al. explores and quantifies stress factors through interviews with flight instructors and the application of the Analytical Hierarchy Process (AHP), revealing personal factors, organizational factors, and environmental factors as key contributors to stress[9]. These studies emphasize the multifaceted nature of stress factors in pilot training and the importance of addressing them to improve both training efficiency and flight safety.

The elevated stress levels among trainees, influenced by a combination of objective and human factors, can partially impact the efficacy of flight training and pose a risk to flight safety[10]. Among the various multi-factor analysis methods, such as AHP and principal component analysis, the combined use of Decision-Making Trial and Evaluation Laboratory (DEMATEL) and Interpretative Structural Modeling (ISM) facilitates a clear depiction of the relationships among different factors, as well as the levels and functions of these factors within the entire system. The strength of DEMATEL-ISM is to structure and systematize complex factors, making it particularly suitable for analyzing the flight training stress structure model of cadets[11,12].

Constructing an index system of flight training stressors for cadets

Stress reaction analysis. Pilot cadets undergoing flight training often exhibit a multifaceted stress reaction characterized by various physiological, psychological, and behavioral manifestations. Physiologically, they may experience symptoms like nausea and insomnia, leading to a decline in their overall physical health. Psychologically, the stress often manifests as negative emotions, including tension and anxiety, which can adversely affect their mental health. Behaviorally, the impact of stress is observed in their training performance, where it can lead to rough movements, a propensity for errors in training operations, and even an aversion to flying[13]. These combined effects highlight the need for effective stress management strategies in pilot training programs to ensure the well-being and proficiency of cadets.

Establishing an index system of stressors. In alignment with the classic SHEL (Software, Hardware, Environment, Liveware) safety model, the stressors for pilot cadets have been categorized into five distinct groups: flight training load (Hardware to Individual), flight safety state (Software to Individual), training environment (Environment to Individual), interpersonal influence (Others to Individual), and personal state (Liveware to Liveware).

The methodology included interviews with 28 trainees from an aviation school, encompassing those currently in training, those who have completed training, and some who have been terminated from training. The interviews consisted of open-ended questions aimed at identifying the various stressors encountered during training. These questions covered areas such as stressful stages in training, factors affecting training performance, and concerns during the training phase. From the data gathered, stressors mentioned by the trainees were extracted and organized. The clarity and relevance of these stressor indicators were also critically evaluated, leading to the elimination of indicators with ambiguous expressions or overlapping scopes. This process was informed by previous research[14], initially obtaining 20 stressor indicators.

Further refinement was achieved through discussion with flight instructors and commercial pilots. Their professional insights led to revisions in the names and meanings of these indicators, ensuring they were described in professional terms. This collaboration also facilitated the consolidation of similar items, ultimately resulting in a set of 18 official stressor indicators, which are detailed in Table 1. This structured approach provides a comprehensive and professionally validated framework for understanding and addressing the stressors faced by pilot cadets in their training.

Table 1: Index system of stressors for pilot cadets in flight training

1st level index	2nd level index	No.	Meaning
Training	Pre-flight preparation	a_1	Lack of information, inadequate preparation, etc.
	Airworthiness of the aircraft	a_2	Inoperative external or internal system of the aircraft
	Progress of flight training	a_3	Slowed or stalled flight training
	Difficulty of flight training	a_4	Too difficult flight training
	Emergency situation	a_5	Instrument failure, bird strike, etc.
Safety	Occurred unsafe incidents	a_6	Recent occurrence of a flight accident or incident, such as air crash, etc.
	Safety regulations of flight training school	a_7	Safety management system (SMS) including SOPs, procedures, standards, etc.
	Weather condition	a_8	Bad weather conditions at airports and air routes

Environment	Cockpit environment	a_9	Cockpit noise, air pressure, etc.
	Complexity of instrument and control system	a_{10}	Different instrument and control system complexity
	Communication with ATC	a_{11}	Poor communication with ATC
	Living conditions in flight training school	a_{12}	Poor living conditions in flight training school
Relationship	Relationship with instructor	a_{13}	Interpersonal relationship with instructor
	Relationship with classmates and friends	a_{14}	Interpersonal relationship with classmates and friends
	Relationship with family	a_{15}	Close relationship with family member
Status	Physical condition	a_{16}	Poor physical condition
	Psychological pressure	a_{17}	Psychological bear of training and life pressure
	Personal finance	a_{18}	Poor personal financial status

DEMATEL-ISM Modeling Methodology

To evaluate the stress reactions of pilot cadets during flight training, this study proposes the utilization of the DEMATEL-ISM method to analyze the 18 identified stressors across five categories. This method is employed to construct a structured model of stress within cadet flight training, allowing for a clear hierarchical delineation of each stressor within the system.

Establishment of the direct influence matrix. Let us define M as the number of consulting experts and n as the number of stressor indicators within the index system of stressors. We solicit each expert to assess the influence of indicator a_i on indicator a_j, using a scale where '0' denotes no influence, '1' indicates weak influence, '2' signifies moderate influence, '3' represents strong influence, and '4' reflects extremely strong influence. The influence score assigned by the k^{th} expert from this evaluation for the influence of indicator a_i on a_j is denoted as x_{ij}^{k} . By averaging the scores across all experts, we obtain the initial direct influence matrix $\boldsymbol{A}_0$, which is an $n \times n$ matrix representing the collective expert assessment of the stressor indicators' interrelations:

$$\beta_{ij}^{k} = \frac{1}{K}\sum_{k=1}^{K} x_{ij}^{k} \tag{1}$$

To mitigate observer bias in the selection of experts for the evaluation process, a diverse group of 16 individuals was invited to participate. This group was composed of four categories of professionals, each with over five years of experience: flight theory teachers, psychology instructors, flight trainers, and airline pilots. Upon collecting and averaging the initial scores from these experts, the Delphi method was employed. This iterative process involved feeding back the results to the experts for review and gathering their opinions for a consensus. Adjustments were made to the scores where there was obvious divergence, and through two rounds of this consultative process, a consensus among the experts was reached. The finalized direct influence matrix, $\boldsymbol{A} = [\beta_{ij}]_{18\times18}$,was then established, as presented in Table 2.

Table 2: The direct influence matrix $\boldsymbol{A}$

β_{ij}	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}	a_{17}	a_{18}
a_1	0.0	0.5	3.0	2.4	1.2	0.0	1.6	0.0	0.7	2.0	3.0	0.0	2.5	1.0	0.5	1.0	3.2	0.0
a_2	1.4	0.0	3.5	3.1	2.2	0.8	1.6	0.0	2.0	2.5	2.0	0.0	1.5	0.5	0.5	1.0	3.0	0.0
a_3	1.5	1.0	0.0	2.5	0.5	0.0	2.0	0.0	0.5	0.5	0.5	0.0	3.5	2.5	2.0	1.5	3.5	1.2
a_4	2.0	1.0	3.0	0.0	1.0	0.0	2.5	0.0	2.0	2.0	2.0	0.0	2.5	1.5	1.5	2.0	4.0	0.6
a_5	3.0	2.5	3.5	3.5	0.0	1.0	3.0	0.5	2.0	2.0	3.0	0.5	3.0	1.0	2.0	2.5	4.0	0.5
a_6	3.0	3.0	3.0	2.5	2.0	0.0	4.0	0.5	1.0	1.0	2.0	1.0	2.0	1.5	2.0	1.5	3.0	0.5
a_7	3.6	3.0	3.5	3.0	3.0	1.0	0.0	0.0	1.0	1.0	2.0	2.0	2.5	2.0	1.0	1.5	3.0	0.0
a_8	3.5	3.0	4.0	4.0	3.6	1.5	2.0	0.0	2.5	1.0	2.5	2.5	1.5	1.0	0.5	2.5	3.5	0.0
a_9	1.0	0.5	1.5	2.0	1.5	0.0	1.2	0.0	0.0	1.5	2.0	0.0	2.0	0.5	0.0	2.0	3.0	0.0
a_{10}	1.0	0.5	2.5	3.5	1.0	0.5	1.0	0.0	1.0	0.0	2.5	0.0	2.0	1.5	0.0	1.0	3.5	0.0

a_{11}	0.5	0.5	2.0	2.5	0.5	0.5	0.8	0.0	1.5	1.0	0.0	0.0	1.5	1.0	0.0	1.0	3.0	0.0
a_{12}	1.0	0.0	1.5	1.0	0.5	0.0	1.6	0.0	0.5	0.5	0.5	0.0	3.3	2.5	1.0	3.0	2.5	0.5
a_{13}	2.0	0.5	3.5	3.0	0.5	0.5	1.5	0.0	1.5	2.5	1.5	2.0	0.0	2.5	1.0	1.5	3.0	1.0
a_{14}	1.0	0.0	1.5	1.0	0.0	0.0	0.5	0.0	0.5	1.0	1.0	2.0	2.0	0.0	1.0	1.0	2.5	1.0
a_{15}	0.5	0.0	1.0	0.5	0.0	0.0	0.5	0.0	0.0	0.0	0.5	1.0	1.5	1.5	0.0	1.0	2.0	3.0
a_{16}	2.5	0.0	3.0	2.5	2.0	0.0	0.5	0.0	2.0	1.5	1.5	0.5	2.0	1.5	2.0	0.0	3.0	1.0
a_{17}	3.5	0.5	3.0	2.5	1.0	0.5	1.0	0.0	2.0	2.0	2.5	0.5	3.0	2.0	2.5	2.5	0.0	1.0
a_{18}	0.5	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	1.5	1.0	1.5	1.5	1.5	2.2	0.0

Establishment of the normalized influence matrix. The initial direct infuence matrix ***A*** is normalized to obtain the normalized infuence matrix ***D*** using Eq. 2 and Eq. 3, where $d_{ij} \in [0,1]$.

$$s = \max_{1 \le i \le 18} \sum_{j=1}^{18} b_{ij} \tag{2}$$

$$\boldsymbol{D} = [d_{ij}]_{18\times18} = \frac{\boldsymbol{A}}{s} \tag{3}$$

Establishment of the comprehensive influence matrix. The comprehensive influence matrix ***T*** reflects the relationship including both direct influence and indirect influence of each indicator in the system of flight training stressors for pilot cadets, which is computed by Eq. 4

$$\boldsymbol{T} = [t_{ij}]_{18\times18} = \boldsymbol{D}(\boldsymbol{I} - \boldsymbol{D})^{-1} \tag{4}$$

where ***I*** represents the n × n identity matrix.

Calculation of influencing degree, influenced degree, centrality, and causality. Let us define the vectors ***r*** and ***c*** as the sums of the rows and columns, respectively, within the comprehensive influence matrix ***T***, as shown in Eq. 5 and Eq. 6.

$$\boldsymbol{r} = [r_i]_{18\times1} = \left(\sum_{j=1}^{18} t_{ij}\right)_{18\times1} \tag{5}$$

$$\boldsymbol{c} = [c_j]_{18\times1} = \left(\sum_{i=1}^{18} t_{ij}\right)_{18\times1} \tag{6}$$

Specifically, r_i denotes the sum of elements in row i of matrix ***T***, encapsulating the cumulative impact that the indicator a_i exerts on all other indicators within the system—this is termed the influencing degree. Meanwhile, c_j is the sum of elements in column j of matrix ***T***, quantifying the collective influence that other indicators impart on a_j—this is known as the influenced degree. When $i=j$, the quantity (r_i+c_j) represents the centrality M_i of indicator a_i, reflecting the total influence, both exerted and received, by a_i within the system. On the other hand, (r_i-c_j) yields the net impact or the causality N_i, indicating the extent to which indicator a_i acts as a driving force within the system.

The subsequent step involves calculating the values of influencing degree r_i, influenced degree c_i, centrality M_i along with its ranking, and causality N_i with its ranking for each indicator (i=1, 2, ...,18), the results of which are presented in Table 3.

Table 3: Infuencing degree, infuenced degree, centrality, and causality of stressors

	Influencing degree (r_i)	Influenced degree (c_i)	Centrality (M_i)	M_i Order	Causality (N_i)	N_i Order
a_1	1.54	2.13	3.67	7	-0.59	12
a_2	1.78	0.97	2.75	13	0.81	4
a_3	1.54	2.93	4.47	3	-1.39	17
a_4	1.84	2.64	4.48	2	-0.80	15
a_5	2.53	1.25	3.77	6	1.28	3
a_6	2.30	0.38	2.68	15	1.92	2
a_7	2.25	1.64	3.90	5	0.61	5
a_8	2.72	0.05	2.77	12	2.67	1
a_9	1.31	1.43	2.74	14	-0.12	8

a_{10}	1.48	1.62	3.10	10	-0.14	9
a_{11}	1.14	1.99	3.13	9	-0.86	16
a_{12}	1.33	0.82	2.15	17	0.51	6
a_{13}	1.82	2.61	4.42	4	-0.79	13
a_{14}	1.03	1.82	2.85	11	-0.79	13
a_{15}	0.80	1.38	2.18	16	-0.58	11
a_{16}	1.67	1.86	3.53	8	-0.19	10
a_{17}	1.92	3.43	5.35	1	-1.51	18
a_{18}	0.73	0.78	1.51	18	-0.05	7

The cause-and-effect relationship diagram. Based on the data presented in Table 3, a cause-and-effect relationship diagram is constructed, as illustrated in Figure 1. In this diagram, if the causality N_i is greater than zero, the corresponding stressor indicator is identified as a cause stressor, signifying that the indicator exerts a significant influence on the other indicators within the system. Conversely, if the causality N_i is less than zero, the indicator is classified as an effect stressor, indicating that the indicator is more influenced by other indicators than it influences them. The magnitude of each circle in the diagram is scaled to be directly proportional to the absolute value of the centrality times the causality of the indicator, visually representing the relative impact of each stressor indicator within the overall system.

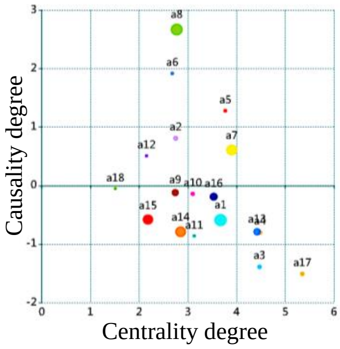

Figure 1. The cause-and-effect relationship diagram of stressors

Establishment of the reachability matrix. We introduce the total influence matrix $\boldsymbol{H}$, as expressed in Eq.7,

$$\boldsymbol{H} = [h_{ij}]_{18\times 18} = \boldsymbol{I} + \boldsymbol{T} \tag{7}$$

where $\boldsymbol{I}$ represents the identity matrix. To determine the reachability matrix $\boldsymbol{K}$, $\boldsymbol{K} = [k_{ij}]_{18\times 18}$, an appropriate threshold λ is selected, as shown in Eq. 8.

$$k_{ij} = \begin{cases} 1, h_{ij} \geq \lambda\left(i, j = 1, 2, \ldots, 18\right) \\ 2, h_{ij} < \lambda\left(i, j = 1, 2, \ldots, 18\right) \end{cases} \tag{8}$$

The rationale for setting a threshold value λ is to filter out the relatively weak influence relationships between indicators, thereby simplifying the complexity of the system for analysis. The choice of λ significantly influences the resulting complexity of the system structure. A larger λ value yields a more straightforward system hierarchy, albeit at a less detailed description of the interactions between stressors. Conversely, a smaller λ value results in a more complex system level, which may compromise the system's integrity due to overcomplication. After careful consideration and validation, it was determined that a threshold λ of 0.1 effectively balances detail with clarity, resulting in a stress structure model that is divided into seven distinct levels.

Establishment of the multi-level hierarchical model. Utilizing the reachability matrix ***K***, we can ascertain the reachable set R_i and the antecedent set S_i of the stress system through Eq. 9 and Eq.10, respectively, which are critical for understanding the hierarchical positioning of each indicator within the system.

$$R_i = \{a_j \mid a_j \in A, k_{ij} \neq 0\}\ (j = 1, 2, \ldots, 18) \tag{9}$$

$$S_i = \{a_i \mid a_i \in A, k_{ij} \neq 0\}\ (i = 1, 2, \ldots, 18) \tag{10}$$

For a given indicator a_i, if $R_i = R_i \cap S_i\ (i = 1, 2, \ldots, 18)$, this indicates that a_i occupies an upper level within the system's hierarchy. To refine the hierarchical structure, indicator a_i is then extracted, and the corresponding row i and column i are removed from the matrix ***K***. This iterative process is continued until all indicators have been extracted, culminating in a hierarchical structure model of flight training stress for cadets. The resultant model, depicting the tiered layout of stressors within the system, is displayed in Figure 2.

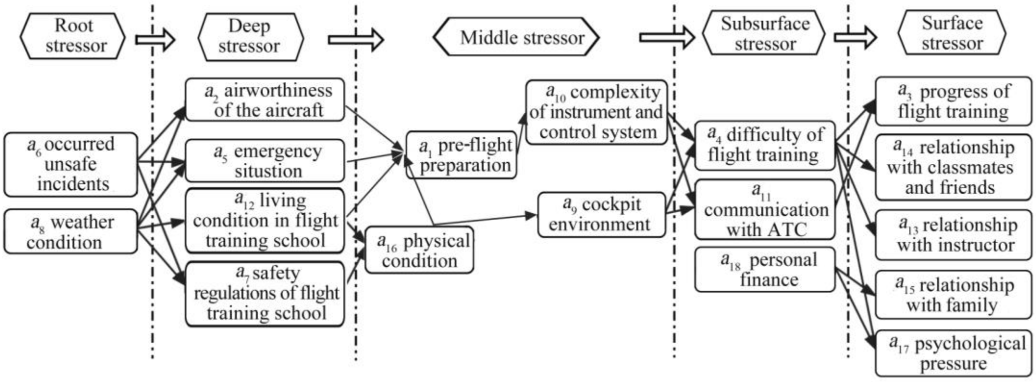

Figure 2. The hierarchical structure model of flight training stress for pilot cadets

The analysis of the structure model of flight training stressors

The causality degree analysis.

The sequence of cause stressors, in N_i order, is weather conditions (a_8), occurred unsafe incidents (a_6), emergency situations (a_5), airworthiness of the aircraft (a_2), living conditions in flight training school (a_{12}), and safety regulations of flight training school (a_7). Notably, a_8 and a_6 are positioned at the root level of the hierarchical structure model. The occurrence of unsafe incidents is a root cause of stress. Such incidents deliver a direct and potent stimulus to student pilots, impacting not only their immediate psychological state but also the broader safety management culture within the aviation school. Flight training schools should enforce stringent management and adhere to civil aviation regulations to prevent incidents that could be symptomatic of safety breaches. Additionally, adverse weather conditions present unavoidable stressors and are also categorized as root causes due to their unpredictability and the significant challenges they pose to flight operations.

The second layer of the hierarchical structure model contains deep stressors such as a_5, a_2, a_{12}, and a_7. The airworthiness of aircraft, influenced by prior maintenance and flight tasks, and may also be affected by unforeseen emergencies like bird strikes. For student pilots, particularly those with limited flight experience, such contingencies can significantly elevate training difficulty, psychological pressure, and consequent stress levels. Therefore, emphasis on ground theory education and pre-flight preparations are crucial for ensuring flight safety and reducing cadet stress. Moreover, robust safety management within aviation schools is essential to reduce human error during flight operations, thereby diminishing the psychological burden on students.

The sequence of effect stressors, in reverse N_i order, is psychological pressure (a_{17}), progress of flight training (a_3), communication with ATC (a_{11}), relationship with classmates and friends (a_{14}), difficulty of flight training (a_4), relationship with instructor (a_{13}), relationship with family (a_{15}), pre-flight preparation (a_1), physical condition (a_{16}), complexity of instrument and control system (a_{10}), and personal finance (a_{18}). The predominant source of direct stress is the interpersonal relationships surrounding the pilot cadets. Therefore, increasing support and closeness from those around the student pilots, particularly through regular communication and encouragement from classmates and instructors, can effectively alleviate their psychological stress.

The progress of flight training (a_3) is another significant surface stressor. Interviews with students highlight concerns about prolonged training durations for single subjects, fearing being grounded and consequent psychological stress. To address this, aviation schools should manage the training schedule effectively, ensuring optimal allocation of resources such as instructors and aircraft to prevent obstruction in training. This approach will not only streamline the training process but also significantly reduce the stress associated with delayed or prolonged training periods.

The centrality degree analysis.

The analysis of centrality degree identifies several key factors with substantial centrality, psychological pressure (a_{17}), difficulty of flight training (a_4), progress of flight training (a_3), and relationship with instructor (a_{13}). Psychological pressure (a_{17}) emerges as the most crucial stressor, which is both a surface and a result stressor, indicating its immediate and consequential nature. The psychological strain on trainees stems from various sources, including familial expectations, comparisons with peers, the training workload, and environmental impacts. The confluence of these factors intensifies the psychological burden, exacerbating stress and subsequently affecting flight training performance.

Difficulty of flight training (a_4) and progress of flight training (a_3), are also classified as surface and result stressors, influenced by objective environmental factors such as weather and aircraft facilities. Cadets often experience tension and anxiety when faced with challenging training tasks. Relationship with instructor (a_{13}) focuses on the influence of instructors, highlighting their role as more central than that of peers or family members in the interpersonal relationships of pilot cadets. Instructors, therefore, have a dual role: imparting training skills and providing emotional support to alleviate student stress, aiding in their successful completion of training.

Conclusion

Based on the SHEL model, the stressors in flight training are categorized into five domains: training load, safety state, training environment, interpersonal influence, and personal state, encompassing a total of 18 identified stressors. Utilizing the DEMATEL-ISM method, a multi-level hierarchical structure model of these stressors for cadets was developed and analyzed in depth. The findings offer valuable insights for the management of cadet flight training and pilot training overall:

a) Emphasis on Theoretical Study and Preparation: It is crucial for flight trainees to prioritize their theoretical studies, and thoroughly prepare before each flight. This preparation not only ensures safety but also builds confidence and reduces stress during actual flight operations.

b) Strengthening Safety Controls in Aviation Schools: Aviation schools need to intensify their focus on safety controls and actively train students in emergency response capabilities. This approach not only enhances the safety environment but also prepares students to handle unexpected situations.

c) Positive Social Influences: Encouraging positive interactions and support from individuals around pilot students, can be an effective strategy to mitigate psychological stress. This support network plays a crucial role in providing emotional support throughout the training process.

d) Instructor's Role in Stress Management: Instructors should be particularly attentive to the stress levels of their students, especially during challenging training phases or when progress is hindered. Providing timely support, can soothing communication can be beneficial in helping cadets manage stress. This support is instrumental in ensuring cadets complete their flight training, as it addresses both the technical and psychological aspects of their development.

Funding Statement

This research was supported in part by the Fundamental Research Funds for the Central Universities , No. 3122022053, and in part by the Scientific Research Projects of Tianjin Educational Committee, No. 2023KJ223.

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Biography

Furong Jiang was born in China. She received the B.S. degree in electronic information engineering and the M.S. degree in electrical engineering from Zhejiang University, China, in 2014 and 2017, respectively. She participated in the Double M.S. Degree Program at École Centrale de Nantes (ECN), France, from 2012 to 2014, where she earned an Engineering Diploma in 2017. Currently, she is a lecturer at the Flight Academy of the Civil Aviation University of China (CAUC) and is pursuing a Ph.D. in safety science and engineering at CAUC. Her research interests include aviation safety and air traffic management.

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