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Combatting the Heat: Assessing Heat Stress Risks in Aircraft Maintenance Environments

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ABSTRACT

Aviation maintenance plays crucial role to the safety and efficiency of air transportation. However, professionals in this field face various hazards, including chemical exposure and extreme temperatures. Heat stress is a significant challenge, particularly in tropical regions where high temperatures can cause physical fatigue, cognitive decline, and an increased risk of human errors, potentially leading to catastrophic aircraft accidents. Proper hazard control measures are essential for preventing injuries and ensuring safe operations. This paper investigates the effects of heat stress on aviation mechanics in a tropical environment and proposes engineering and administrative controls to mitigate its impact. The primary research question is examining whether mechanics working in smaller hangars in tropical regions have a high risk of heat-related injuries. The study was conducted in a flight maintenance hangar located in Florida, USA, where 18 full-time aviation mechanics worked day shifts performing scheduled and unscheduled maintenance on various type of aircrafts. Environmental monitoring was completed using the REED R6200 WBGT Heat Stress Monitor to measure heat exposure levels. Data was collected across different sections of the hangar to identify heat stress risks and compared to the American Conference of Governmental and Industrial Hygienists (ACGIH) Threshold Limit Values (TLV). The study findings showed that the average Wet Bulb Globe Temperature (WBGT) recorded in the hangar was 27 $\pm$ 0.8 °C, closely approaching the ACGIH TLV of 27.5 °C. Considering a metabolic workload of 415 Watts, this WBGT level indicates a high risk of heat-related injuries. ACGIH guidelines recommend a 50% work and 50% rest schedule per hour under such conditions to mitigate heat stress. Furthermore, certain sections of the hangar were identified as excessively hot, necessitating work restrictions or significant engineering controls in those areas. The findings suggest the urgent need for interventions to reduce heat stress risks in aviation maintenance hangars. The recorded WBGT levels, combined with strenuous workload demands, indicate that mechanics operate under potentially hazardous conditions. To safeguard worker health and prevent heat-related injuries, it is vital to implement structured work/rest schedules and robust engineering controls. These measures may include enhancing ventilation, deploying cooling systems, or modifying work hours to avoid peak heat periods. Proactive heat stress management is essential to ensuring a safer working environment. Continuous monitoring and refinement of heat stress protocols can help reduce the likelihood of heat-related injuries and prevent maintenance errors that could lead to aviation disasters. Addressing these challenges will protect workers' health while minimizing the risks associated with heat exposure, ultimately contributing to safer aviation operations.

Keywords: WBGT, Heat stress, Fatigue, Aircraft maintenance hangar, Aviation mechanics

INTRODUCTION

Aviation maintenance plays an essential role in ensuring the safety, reliability, and operational efficiency of air transport systems. Aviation maintenance technicians (AMTs) conduct regular inspections, repairs, and maintenance of aircraft to ensure compliance with the rigorous safety regulations governing air travel. However, AMTs face several occupational hazards, including physical risks from machinery, exposure to toxic chemicals, and the potential risks associated with thermal stress (Shah et al., 2018). One of the most significant hazards in aviation maintenance is heat exposure, especially in tropical areas where elevated temperatures and increased humidity aggravate the physical challenges faced by AMTS (Ferrer et al., 2021). In tropical areas, aviation maintenance hangars are subjected to elevated ambient temperatures and increased humidity levels, combined with the heat formed by machinery used in maintenance services, such as aircraft engines, electrical systems, and other equipment. Prolonged exposure to such heat can result in severe health issues, such as dehydration, heat exhaustion, heat stroke, and chronic cardiovascular problems (Kipkoech et al., 2020). Furthermore, the physical and cognitive fatigue resulting from heat stress can significantly impair an AMT's ability to execute tasks accurately and efficiently. This situation increases the likelihood of human error, a factor recognized as a significant contributor to aircraft accidents (Kragh et al., 2018). Human errors, especially during aviation maintenance operations, has been a major factor in numerous notable aviation disasters. An example is the 2009 crash of Air France Flight 447, which was partially attributed to maintenance errors on the aircraft and the resulting malfunction of the pitot tubes (Becker et al., 2013). The investigation into this accident indicated that, although weather-related factors were a contributing factor, insufficient training for AMTs and errors in maintenance protocols were also critical elements in the tragedy. Similarly, maintenance errors have been involved in the 2013 crash of Asiana Airlines Flight 214. In this case, inadequate maintenance practices related to the aircraft's auto-throttle system led to the malfunction of critical systems during take-off, culminating in a tragic accident (Lee & Lee, 2016). These examples of aircraft accidents emphasize the necessity for robust hazard management and the ongoing enhancement of aviation maintenance procedures to reduce the risks linked to human error. Heat stress establishes significant risks in aviation maintenance settings due to the physically intensive nature of the work performed. AMTs frequently engage in physically demanding activities, that include lifting heavy parts, crawling into confined spaces, and handling hot machinery and equipment (Park et al., 2020). The combination of physical effort and high ambient temperatures increases the likelihood of thermal fatigue, which adversely impacts not only the physical health of the workers but also their cognitive functions. This decline in cognitive performance can result in errors that may compromise aircraft safety (Neal et al., 2019). Additionally, a research study has shown that heat stress negatively affects reaction times, attention, and memory, key factors essential for executing maintenance tasks that demand a high level of accuracy (Kumar et al., 2017). The need for comprehensive strategies to mitigate heat stress in small aviation maintenance hangars is crucial, especially in tropical areas where the risks are intensified.

This study aims to investigate the effects of heat stress on AMTs working in a tropical area and to propose engineering and administrative measures that can be adopted to mitigate heat-related hazards. The primary research question centres on whether aviation mechanics working in small, poorly ventilated hangars in tropical climates are under elevated risk of heat-related injuries. The significance of this study extends beyond the health and safety of AMTs; it plays a crucial role in minimizing the likelihood of accidents attributable to human error. By pinpointing areas susceptible to heat stress, applying engineering controls, and administrating preventive strategies, it is possible to alleviate the risks linked to human errors in aviation maintenance, thereby enhancing the overall safety of the aviation sector.

METHODS

The assessment of heat stress risk was conducted in a small flight maintenance hangar located in Florida, USA, during March, aligning with the spring season in the Northern Hemisphere. This timeframe was selected to encompass various environmental factors that could lead to heat stress, especially in a tropical climate characterized by elevated temperatures and humidity. During the assessment period, 18 full-time AMTs worked day shifts to perform both scheduled and unscheduled inspections, along with maintenance on different single and multi-engine aircraft. These tasks often involve extended periods of physical exertion, which can increase the risk of heat stress. Environmental monitoring was conducted using the REED R6200 WBGT Heat Stress Meter (Wilmington, NC, USA), a portable instrument designed to utilize thermocouples and hygrometers to measure temperature and humidity at multiple points within the hangar. This device is particularly effective for real-time evaluation of heat stress risks, offering vital information regarding the environmental conditions that affect worker safety (Aviado et al., 2015). The instrument capability to assess both temperature and humidity is crucial, as heat stress is known to be influenced by the interaction of these two factors, as well as radiant heat. The integration of these metrics plays a critical role in determining the comfort and well-being of individuals operating in such settings. To thoroughly assess the potential risk of heat stress, the Wet Bulb Globe Temperature (WBGT) index was calculated. The WBGT index is widely recognized as a reliable indicator for evaluating heat stress, as it considers various environmental factors such as air temperature, humidity, and radiant heat (Ljung et al., 2019). This comprehensive metric offers a more understanding of the body's heat load compared to basic temperature readings, as it includes the effects of heat radiation, which is especially relevant in hangar work settings characterized by extensive metal surfaces and aircraft engines generating radiant heat (Mujtaba et al., 2017). The WBGT index is widely utilized to assess the cumulative impact of environmental stressors on the likelihood of heat-related injuries, serving as a standard in occupational health evaluations (ACGIH, 2022). Data collection took place from noon to 2:00 PM, a timeframe selected for its generally elevated environmental temperatures in Florida. This period was anticipated to experience the peak of daily heat exposure in the hangar, influenced by solar radiation as well as the operation of aircraft and maintenance equipment. Comparative analyses were conducted across various sections of the hangar to assess differences in heat stress risk, as specific areas, particularly those adjacent to aircraft engines or equipment exhausts, are expected to experience higher temperatures than others (Cheung et al., 2015). This assessment facilitated the identification of specific "hotspots" where AMTs may face an increased risk of heat-related injuries. The environmental data gathered were subsequently analyzed in relation to the Threshold Limit Values (TLV) established by the American Conference of Governmental and Industrial Hygienists (ACGIH), which offers evidence-based recommendations for exposure limits to various environmental factors, including heat (ACGIH, 2022). The TLVs for heat stress, as outlined by ACGIH, are based on the WBGT index and serve as a guideline for assessing the risk of heat-related illnesses across different work environments (Hassan et al., 2021). Any data points that exceeded the recommended TLVs suggested an increased risk of heat stress, indicating the need for preventive actions, such as enhanced ventilation or cooling systems, to alleviate potential health impacts on workers.

RESULTS AND DISSCUSSION

The results of this study are consistent with existing literature that highlights the critical need for proactive management of heat stress (Hales et al., 2009; Gomez et al., 2015; Burch et al., 2017). The outcomes of risk analysis conducted in the aviation maintenance hangar indicated an average Wet Bulb Globe Temperature (WBGT) of 27 ± 0.8 °C, which is in line with the Threshold Limit Value (TLV) for heat stress established by the American Conference of Governmental and Industrial Hygienists (ACGIH) at 27.5 °C. The findings suggest that AMTs in the hangar may face conditions that exceed the threshold for heat-related injuries hazards. With a metabolic workload of 415 Watts, the recorded WBGT levels indicate a considerable potential for physiological stress on AMTs operating in these environments. In accordance with ACGIH recommendations, it is advised that under such demanding conditions, a work-rest regimen of 50% work and 50% rest each hour be implemented to alleviate heat stress and avert heat-related injuries (ACGIH, 2022). In addition to the overall WBGT assessment, certain sections of the hangar were found as having temperatures that exceeded acceptable thresholds for safe working conditions. This highlights the importance of monitoring specific hot spots within the workspace, where either work should be limited or additional control measures, such as engineering controls, should be implemented. These findings align with research conducted in similar environments, such as the study by Gomez et al. (2015), which highlighted the risks associated with elevated heat levels in aviation maintenance environments and emphasized the need for control measures, including air ventilation and cooling systems. Elevated WBGT levels, combined with significant metabolic workload, indicate that AMTs may be working in potentially dangerous conditions. These results align with earlier research on heat stress in industrial settings, where WBGT readings at or above the TLV have been linked to a higher incidence of heat-related injuries, such as heat exhaustion, heat stroke, and dehydration (Challoner et al., 2015; Wyon et al., 2018). For example, Burch et al. (2017) found that high WBGT levels in manufacturing settings were associated with an increased risk of heat-related injuries, mirroring the conditions identified in this study. Therefore, it is crucial to implement proactive strategies to mitigate these risks. Adopting a work/rest schedule, as advised by the ACGIH, will enable workers to recuperate during times of increased heat exposure, thereby decreasing the chances of heat-related injuries (ACGIH, 2022).

In addition to the work/rest schedule, other strategies to mitigate heat stress should be considered. The introduction of engineering controls, such as improved ventilation, the installation of air conditioning or evaporative cooling systems, and the reduction of heat sources within the hangar, can contribute significantly to improving the working environment. Previous studies have demonstrated the effectiveness of these interventions in reducing heat exposure and improving worker comfort and safety (Bouskill et al., 2018; Lima et al., 2020). Lin et al. (2016) also evaluated the effectiveness of cooling interventions, such as personal cooling devices and air-conditioning, in industrial settings, suggesting that these approaches could provide substantial benefits for workers exposed to high heat levels. Moreover, modifications to work hours, such as scheduling work during cooler times of the day or implementing shift work to avoid peak heat periods, can further help minimize the risk of heat stress. Froment et al. (2019) similarly emphasized the need for workplace temperature management and adjustments in work schedules to prevent heat-related injuries. The results of this study emphasize the necessity of continuous surveillance of heat stress conditions in high-risk settings such as aviation maintenance hangars. Heat stress is a dynamic issue that fluctuates with seasonal changes and operational requirements. Therefore, it is crucial to establish adaptive heat stress management protocols that include real-time environmental monitoring to ensure the safety of workers (Kjellstrom et al., 2018). Additionally, Xu et al. (2020) highlighted the significance of real-time monitoring for detecting heat stress hazards in high-risk sectors, promoting the integration of advanced technology to address these environmental challenges. Moreover, continuous training and awareness initiatives for AMTs about the signs of heat stress and effective hydration strategies are vital for enabling them to respond appropriately when heat-related symptoms occur.

CONCLUSION

The study findings emphasize the critical necessity for comprehensive approaches to alleviate heat stress in the assessed aviation maintenance hangar. As Wet Bulb Globe Temperature (WBGT) levels approach dangerous limits and AMTs face significant metabolic workload, prompt intervention is vital. To prevent these hazards, it is important to adopt effective measures such as following recommended work/rest cycles, utilizing engineering controls, and modifying work schedules. These actions will greatly reduce heat stress and its related risks.

Moreover, continuous monitoring and improvement of these strategies are vital for enhancing worker safety, decreasing the incidence of heat-related injuries, and reducing the likelihood of maintenance errors that could result in aviation disasters. Furthermore, the adoption of these strategies not only protects the health of AMTs but also aids in preventing errors that could lead to aviation catastrophes, thereby ensuring the safety of both maintenance personnel and aviation operations.

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