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A Study in Aircraft Heating System Trainer Model AS-43 for Aeronautical Engineering Students Practice

Fatin Auni Pisal[1], Nor Adrian Nor Salim[1,2]*

[1]Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

[2]Industrial Hygiene Research Group (IH), Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Corresponding Author

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Abstract: The Model AS-43 heating system trainer is a fully operational model of a light aircraft heating system demonstrating the combustion air heater method. Heat transfer is related to the mechanism that happens in this process. This study aims to utilize the trainer Model AS-43 for practical experiments in aeronautical engineering education. The research objectives include developing standard operating procedures, determining system parameters, and proposing improvements. The significance of the study lies in enhancing the teaching scope for aeronautical engineering students and improving the aircraft heating system trainer Model AS-43. The obtained results and calculations serve as valuable data for aeronautical engineering education and can facilitate further analysis and improvements in the field. Recommendations are made to enhance the trainer's utilization, including incorporating appropriate measuring tools. Implementing these recommendations would maximize the trainer's educational potential, allowing it to be utilized as an effective teaching tool for mechanical and aeronautical engineering courses. The proposed changes could improve students' comprehension, promoting better learning outcomes and advancing aviation education.

Keywords: Aircraft heating system, Model AS-43 trainer, heat transfer

1. Introduction

The Model AS-43 Heating System Trainer was a fully operational model of a typical light aircraft heating system, using genuine aircraft parts to demonstrate the combustion air heater method for heating. Aircraft heating systems were essential for maintaining a comfortable cabin temperature for passengers and crew, but they may have some drawbacks like energy inefficiency, noise, and vibration.

Heat was transition energy where the energy transmitted between two systems because of a temperature differential was what this definition means. There were three mechanisms of heat which are conduction, convection, and radiation. Conduction was the process by which, because of particle interaction, the more energetic particles of a substance transmit energy to the surrounding, less energetic particles. Convection was energy that was evacuated from a solid surface to a nearby fluid moving because of the combined effects of conduction and fluid motion. Radiation defines as energy transfer caused by electromagnetic wave emission [1, 2].

Air contains a combination of 23.2% oxygen, 75.5% nitrogen and 1.3% Argon and small amounts of other gases. Used as a heat transfer fluid in hot air heaters. Determination of the heating capacity or cooling system by measuring the amount of heat that must be added (when heating) or removed (when cooling) to maintain the desired temperature in a building or space. The amount of heat added to a given area at a constant temperature should equal the amount of heat lost in heating applications [3].

*Corresponding author: adrian@uthm.edu.my

The optimized results show that the cruise flight hour has little impact on the optimal design variables, while the cabin heat load has an approximately linear relationship with the optimal design variables. The cabin temperature changes, the node temperatures were almost constant, which can be taken as a criterion for the design of each component [4].

The technology of advanced thermal management system (TMS) with energy optimization was becoming more and more important. The advantages of the TMS where the heat transfer route from the heat sources including the hydraulic system, the generator lubrication oil system, the liquid cooling system, and the engine bleed air used for environmental control system to the fuel is optimized. In addition, aircraft waste heat is innovatively used for the anti-icing system. The TMS with energy optimization was one of the options for designing high-performance aircraft [5]. The investigations of three TMS technologies were considered: scoop and flush air inlets, an air-air heat exchanger system with electric fan, and an air-source heat pump. For each of them, models are established to estimate their mass, their possible additional drag, and their contribution to electrical consumption, which are key outputs for overall aircraft design. Air-source heat pump and flush inlet systems were found to be the solutions that cause the least fuel penalty [6].

The effects of icing parameters liquid water content (LWC) and median volume diameter (MVD) and hot air parameters (mass flow rate and temperature) on the thermal performance of an inner-liner anti-icing system with jets impingement heat transfer were analysed in detail by combining impingement and evaporation heat transfer mechanisms. The impingement hot air mass flow rate dramatically affects the heat transfer performance of the impingement stagnation region within the range of the experimental parameters. The temperature of impingement hot air and that of wing skin are approximately linear correlated [7].

Geometric optimization of piccolo tube provides a cost-effective approach to shorten the design circle of hot-air anti-icing system and maximize the utilization efficiency of bleed air. An optimization methodology for aircraft hot-air anti-icing systems based on reduced order method (ROM) was developed. ROM based on proper orthogonal decomposition (POD) and radial basis function neural network (RBF) was constructed to evaluate objective and constraint functions of single- and multi-objective optimizations [9].

From the experimental investigation of air distribution in an airliner cabin mockup with displacement ventilation, the air temperature was stratified, and the air velocity was low. The contaminant was not transported to the other side of the cabin by the displacement ventilation system and was removed effectively through the ceiling exhaust [8].

The cabin heating system in an aircraft is responsible for providing warmth to the passengers and crew and maintaining a safe and comfortable environment inside the cabin. The heating system works by circulating warm air throughout the cabin, which helps to maintain a comfortable cabin temperature, even at high altitudes where the outside temperature can be very cold. Bleed air heating is a system that uses compressed air taken from the engines and heated using a heat exchanger. The heated air was then distributed throughout the cabin using ducts. These systems heat the cabin with high-pressure air from the engine's compressor stage. One of the main benefits of bleed air systems is that they can quickly provide a large amount of heat, making them well-suited for use in high-altitude or cold weather operations [10].

A radioactive heating system was designed to simulate the heat exchanger between the hot gas and the fuel-cooled structure in a scramjet combustor. A flat-plate cooling structure was heated unilaterally using thermal radiation from an electrically heated graphite plate. The system was designed to work at a minimum heat flux of 1.5 MW/M^2 at an effective heating area up to 1000 mm × 40 mm. The system has the capability of providing one-sided high heat flux heating [11].

This study aims to enhance aeronautical engineering students' understanding of aircraft heating systems by using the trainer Model AS-43 in practical experiments. The research objectives include developing standard operating procedures and safety guidelines for the trainer and determining the heating system's characteristics. The study seeks to add value to the aircraft heating system trainer Model AS-43 in aeronautical engineering education and improve the teaching syllabus. The scope of the research is limited to the AS-43 trainer, using jet A or white kerosene as fuel, and focusing on the combustion for heater method for heating.

In summary, the functionality and importance of the Model AS-43 heating system trainer, the significance of aircraft heating systems in maintaining a comfortable environment for passengers and crew, and the research objectives to enhance students' learning experience and safety measures while using the trainer.

2. Methodology

In the context of the research being discussed, the methodology used is detailed and explained. Various data-gathering techniques were employed to enhance the validity of the findings. Additionally, the research incorporates the use of a standard operating procedure and hierarchy of hazard controls to analyze the heating system of the aircraft trainer, providing a comprehensive understanding of the subject. This Fig. 1 shows schematic diagram of a Model AS-43 heating trainer system that will be used as reference to operate the system in this study.

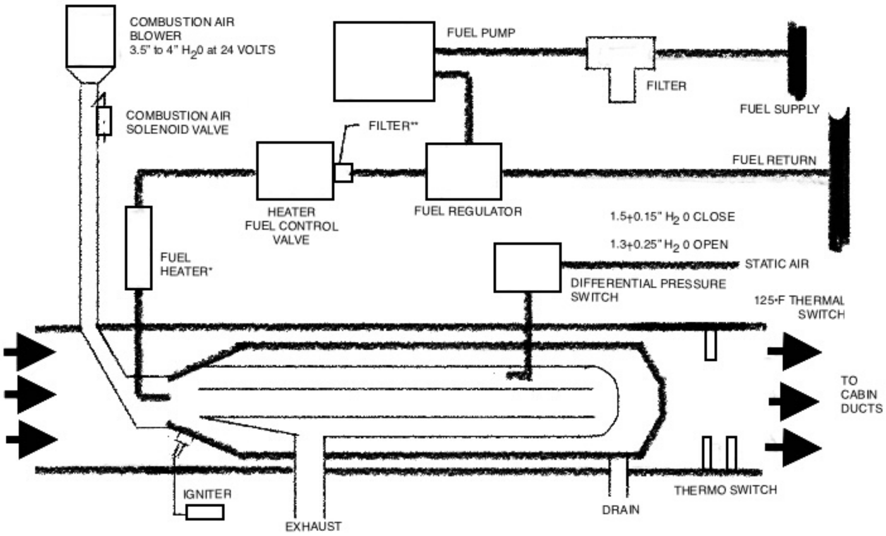

Fig. 1 - Schematic diagram of Model AS-43 trainer heating system

2.2 Data Acquisition

The data is collected through the test conducted in the laboratory. Two devices are used to measure the temperature and relative humidity. The research utilized the Q-Track Plus and TC-08 Data Logger devices to measure temperature and relative humidity in the AS-43 aircraft heating trainer system. The TC-08 Data Logger with a thermocouple type K provided accurate temperature measurements, and the Q-Track Plus device rapidly detected relative humidity with high precision. The study focused on temperature change, measured before and after the combustion chamber, and considered thermal insulation to account for heat loss or gain through cabin walls. Relative humidity, impacting passenger comfort and electronic equipment, is measured and can be controlled through dehumidification or humidification units. The psychometric link between temperature and relative humidity was considered, and water vapor mass calculation considered the varying air pressure inside the aircraft cabin during flight.

Evaluation of heat transmission over a pipe or heat exchanger tube wall is more challenging. The heat transmission surface area is continuously rising or decreasing along a cylindrical wall. Fig. 2 shows the cross-section of a pipe made of a single material.

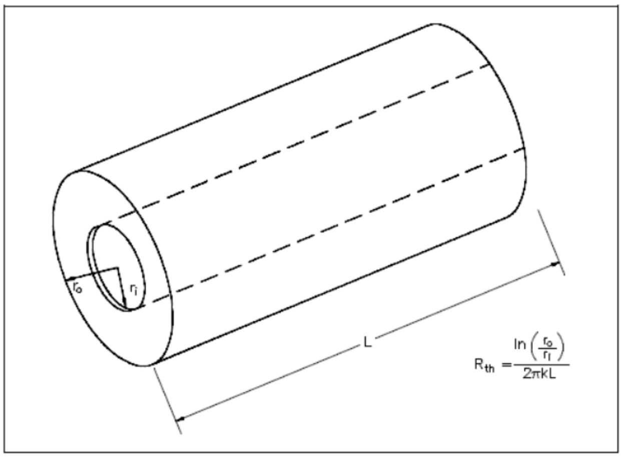

Fig. 2 - Surface area in cross section of a cylindrical pipe

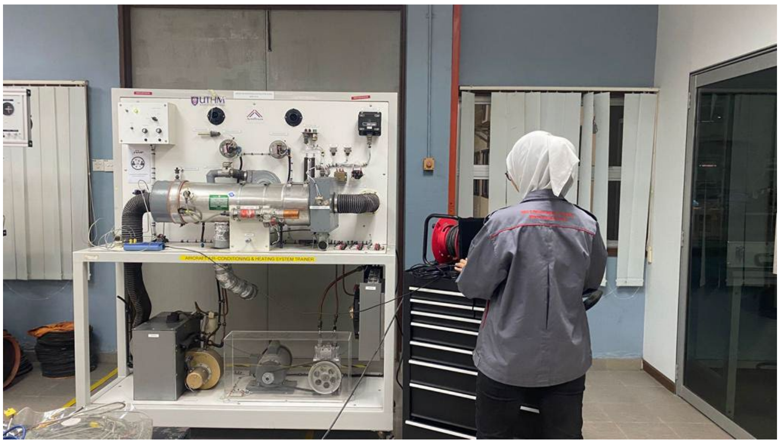

Fig. 3 - Temperature and relative humidity measurement of Model AS-43 heating system trainer

The temperature change in this study was measured using TC-08 Data Logger is the thermocouple type K to get the data needed. Based on the Fig. 3 below shows where the inlet temperature (T_0) measured is before the combustion chamber and the outlet temperature (T_1) is after the combustion chamber. In the case of an aircraft heating system, the system is the air inside the cabin. The heat contributed to the system is the heat created by the heating system, and the system's mass is the cabin's air mass. Air's specific heat capacity is about 1.005 J/g°C.

Fourier's Law of Conduction is the most typical method of correlation in conduction heat transfer. The rule is most often employed in cylinder form (cylinders), which are shown below, when it is expressed as an equation [1].

$$\dot{Q} = kA\left(\frac{\Delta T}{\Delta r}\right) \tag{1}$$

Where,

$\dot{Q}$ = rate of heat transfer (Btu/hr)

A = cross sectional area of heat transfer (ft^2)

Δr = thickness of cylindrical wall (ft)

ΔT = temperature difference (°F)

k = thermal conductivity $(Btu/ft - hr - °F)$

The radius (r) and length (L) of the pipe have a direct relationship with the surface area (A) for heat transmission via the pipe (ignoring the pipe ends). The region for heat transmission rises as the radius widens from the inner wall to the outside wall [1].

$$A = 2\pi rL \tag{2}$$

Fourier's law serves as the starting point for the formulation of an equation estimating heat transport through an object having cylindrical shape [1].

$$\dot{Q} = kA\left(\frac{\Delta T}{\Delta r}\right) \tag{3}$$

It is clear from the debate above that there is no one precise definition of area. The problem cannot be solved using only the area of the outer surface or the area of the inner surface. A log mean cross-sectional area must be defined for a cylindrical geometry issue [1].

$$A_{lm} = \frac{A_{outer} - A_{inner}}{\ln\left(\frac{A_{outer}}{A_{inner}}\right)} \tag{4}$$

The log mean area may be computed from the inner and outer radius without first computing the inner and outer area by substituting the formula 2πL for area in Equation above [1].

$$A_{lm} = \frac{2\pi\, r_{outer}L - 2\pi\, r_{inner}L}{\ln\left(\frac{2\pi\, r_{outer}L}{2\pi\, r_{inner}L}\right)}$$

$$= 2\pi\, L\left(\frac{r_{outer} - r_{inner}}{\ln\frac{r_{outer}}{r_{inner}}}\right) \tag{5}$$

Equation heat transferred by conduction may be modified to include this formula for log mean area, which enables us to determine the heat transfer rate for cylinder shapes [1].

$$\dot{Q} = k\, A_{lm}\left(\frac{\Delta T}{\Delta r}\right)$$

$$= k\left[2\pi L\frac{(r_o - r_i)}{\ln(r_o/r_i)}\right]\left(\frac{T_0 - T_1}{r_o - r_i}\right)$$

$$\dot{Q} = \frac{2\pi\, k\, L\,(\Delta T)}{\ln(r_o/r_i)} \tag{6}$$

Where,
L = length of the pipe (ft)
r_i = inner radius (ft)
r_o = outer radius (ft)

The Heat Loss Per Foot of Length [1].

$$\frac{\dot{Q}}{L} = \frac{2\pi(T_{rt} - T_i)}{\left[\frac{\ln\frac{r_i}{r_o}}{k_s}\right]} \tag{7}$$

Where,
T_{rt} = room temperature (°F)
T_i = inner temperature (°F)
k_s = thermal conductivity of stainless steel ($Btu/ft - hr -$ °F)

2.2 Hierarchy of Hazard Controls

Elimination would involve eliminating the need for a heating system by designing aircraft that do not require heating. For example, some military aircraft are designed to operate in extreme temperatures and do not require heating systems.

Substitution might involve using alternative heating systems that are less hazardous. For example, instead of using a heating system that uses toxic chemicals, a system could be designed that uses electric heating elements or hot air circulation.

Engineering controls could involve designing the heating system, making it less likely to fail or malfunction. For example, adding redundant systems or sensors to detect and respond to problems or designing the system to be easily accessible for maintenance and inspection.

Administrative controls could involve implementing procedures for the operation and maintenance of the heating system to reduce the risk of failure or malfunction. For example, establishing regular maintenance schedules and inspection procedures and training operators and maintenance personnel on how to operate and maintain the system safely.

Personal Protective Equipment (PPE) would involve providing equipment such as self-contained breathing apparatus (SCBA) and fire-retardant clothing to protect workers in an emergency. This should be the last line of defence and is less effective than the other controls.

It is important to note that the specific controls used will depend on the type of heating system and the specific hazards it poses. A thorough risk assessment should be conducted to identify the hazards associated with the heating system and the most appropriate controls for mitigating those hazards. Regular maintenance and inspections are crucial to minimizing the risk of hazards in the heating system.

3. Results and Discussion

The data collected are divided into two sections which are manual heat mode and auto heat mode. From the data obtained, the attention has been aimed to analyse and discuss the detailed mechanical and physical properties of the model AS-43 of aircraft trainer heating system with verified and calibrated by supporting from previous literature. As significant, data recorded of result findings can be defined as **Table 1** and calculation carried out to analyse the aircraft trainer of compatibility to be operated.

Table 1 - Experimental data

Switch	Manual heat	Auto heat
Inlet air before combustion temperature, T2 (℃)	25°C	25.7°C
Outlet air after combustion temperature, T3 (℃)	38.4°C	38.5°C
Relative Humidity before, Rh1	44%	46.6%
Relative Humidity after, Rh2	45.3%	48.1%
Temperature difference, ΔT_H (°C)	6.4°C	5.3°C
Heat transfer rate, $W/m^2.°C$	$3.42 \times 10^5\ W/m^2.°C$	$3.26 \times 10^5\ W/m^2.°C$
Heat loss, $W/m^2.°C$	$-2.51 \times 10^5\ W/m^2.°C$	$-2.57 \times 10^5\ W/m^2.°C$

The inlet air temperature for the manual heat mode is 25°C, and the outlet air temperature increased to 38.4°C, according to the findings. Before and after combustion, the equivalent relative humidity levels are 44% and 45.3%, respectively. These numbers show that the heating system successfully boosted the output temperature while keeping the relative humidity comparatively constant. It implies that the system can be effectively regulated to prevent too dry or humid situations, which might be dangerous for both the aircraft and its people.

The computed heat transfer rate for the manual heat mode is $3.42 \times 10^5\ W/m^2.°C$, whereas it is somewhat lower for the automatic heat mode at $3.26 \times 10^5\ W/m^2.°C$. These numbers show how well the heating system transfers heat to the output air. The findings show that the manual mode had a somewhat greater heat transmission rate, indicating that manual control could provide more accurate modifications depending on current circumstances.

The heating system able to efficiently retain heat based on the negative heat loss values obtained for the manual and auto heat modes $-2.51 \times 10^5\ W/m^2.°C$ and $-2.57 \times 10^5\ W/m^2.°C$, respectively. A system that has negative heat loss may preserve and hold heat inside the system, assuring effective energy use and reducing waste.

4. Conclusion

In conclusion, this study successfully achieved its goals of creating standard operating procedures (SOPs) and a hierarchy of hazard controls for the AS-43 aircraft heating system trainer. Important parameters like relative humidity, temperature change, heat transfer rate, and heat loss were identified within the system. The heating system demonstrated efficiency in increasing outlet air temperature while maintaining consistent relative humidity, ensuring a regulated and pleasant atmosphere for aircraft passengers.

Based on the study's findings, the heating system effectively transported heat to the output air, and suggestions were made to further improve system effectiveness and safety. These included implementing automated temperature management, humidity regulation, real-time monitoring, safety controls, and regular maintenance to enhance system performance and mitigate risks.

Aviation professionals can use the SOPs and hazard controls to ensure standardized and safe practices while using and maintaining the AS-43 aircraft heating system trainer, enhancing overall aircraft safety and passenger comfort during flights.

The information from this research will serve as a valuable starting point for future work on heating systems for aircraft, contributing to advancements in aviation technology and ensuring continuous improvements in aircraft performance and safety. The Model AS-43 Heating system trainer can be utilized more effectively for educating students about aircraft heating systems by implementing the suggested enhancements. These include using automated temperature control, integrating humidity sensors, real-time monitoring, and establishing regular maintenance programs. By adopting these changes, the trainer can become a valuable teaching tool for Mechanical and Aeronautical Engineering courses, allowing students to fully implement the hierarchy of hazard controls and SOPs. The study's results suggest that the Model AS-43 Heating system trainer has the potential to be an effective teaching resource.

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