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A Study on Aircraft Air-Conditioning System Trainer Model AS-43 For Aeronautical Engineering Student Practice

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Abstract: Aircraft air conditioning systems are crucial for ensuring a comfortable and safe environment for occupants during flight. These systems regulate temperature, humidity, and air pressure within the cabin and are found in various aircraft types, including commercial airliners, business jets, military aircraft, and helicopters. The objectives of the research are to identify suitable standard operating procedures (SOPs) and safety protocols for the trainer system, and to determine temperature, relative humidity, pressure, and enthalpy changes within the AS-43 system. A varying parameter is temperatures, pressure, relative humidity and the enthalpy can be obtained. Manual Cool and Auto cool mode of the AS-43 trainer are evaluated. The experimental results show the Manual Cool and Auto Cool gives a slightly different enthalpy values and COP for the system. The enthalpy obtained from the Manual cool are between 240 kJ/kg to 450 kJ/kg while Auto Cool enthalpy is between 240 kJ/kg to 440 kJ/kg. The relative humidity of both modes is in average range suggested by ASHRAE. P-h diagram of both experiments can be obtained based on the data collected. Finally, the study focuses on the AS-43 Aircraft Air Conditioning System Trainer Model, which serves as a valuable educational tool for teaching students about aircraft air conditioning systems. Hence, a significant recommendation is suggested discussed at the end of the research.

Keywords: Aircraft air conditioning system, AS-43 trainer model, enthalpy, standard operating procedure, educational tool

1. Introduction

Aircraft air conditioning systems are essential for providing a comfortable and safe environment inside the cabin. It controls temperature, humidity, and air pressure. At the standard cruising altitude of 18,900ft, human survival without adequate protection is not possible inside airplanes (Saim R., 2014). Modern large commercial aircraft are equipped with environmental control systems (ECS), as defined by SAE International (2001), which provide both cold and warm air while controlling pressure, temperature, humidity, and contaminants to ensure crew comfort and equipment integrity. The cooling system in an aircraft uses a compressor to cool the air by circulating refrigerant through a condenser and evaporator.

The objectives of the study are to identify a suitable standard-operating-procedures (SOP) and safety hierarchy for aircraft air conditioning trainer system and to determine the temperature, relative humidity, pressure and enthalpy change of the AS-43 aircraft air conditioning trainer system. Merzvinskas, et. al. (2019) identified that systems that use the vapor compression cycle have a higher cooling capacity on the ground, which allows for better temperature control. However, vapor compression systems, despite having better cooling capacity, are more complex due to the need to

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control the powerful compressor and its tendency to overheat. Alahmer et al. (2011) identified six main factors that affect in-cabin thermal comfort, which can be categorized as either environmental or personal. These systems are designed to control temperature, humidity, and air pressure, as well as to remove harmful gases and particles. According to Cengel and Boles (2006), vapor compression cycle systems are based on a closed refrigeration cycle known as the Rankine cycle operating in reverse. The working fluid, which is a chemical refrigerant, undergoes phase changes during the cycle processes of evaporation and condensation. These processes involve constant temperature and pressure. Additionally, the scope of this study does include demonstrating vapor cycle from AS-43 system.

2. Methodology

The methodology chapter provides a systematic analysis of the methods used in the study. It establishes the validity of the research by ensuring that the methods are appropriate for answering the research questions. The scope of this study involves determining suitable standard operating procedures (SOPs) and safety measures for the aircraft air conditioning trainer system AS-43. The study includes describing the experimental procedures using the trainer model and proposing a lab manual for mechanical and aeronautical engineering students. The focus is on measuring temperature, pressure, and enthalpy changes in the experiment to obtain reliable results.

2.1 Aircraft Air Conditioning System Trainer Model AS-43

The AS-43 aircraft air conditioning system trainer model is a widely utilized tool in the field of aerospace engineering for training and research purposes. It accurately replicates the air conditioning system of an aircraft, encompassing cooling, heating, and ventilation systems. By incorporating genuine aircraft components, the trainer enables instructors to showcase the functions of different system parts and offers students the opportunity to practice troubleshooting various faults.

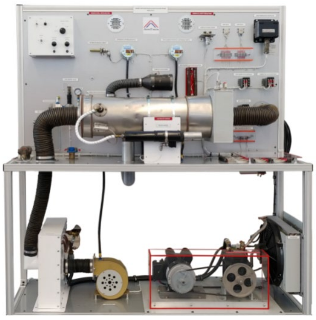

Fig. 1 - Aircraft air conditioning & heating system trainer model AS-43

The AS-43 model is equipped with essential components found in an aircraft air conditioning system, including a vapor cycle compressor, compressor motor, receiver dryer, condenser, and thermal switch. For simulating the heating system, it incorporates a combustion chamber, fuel tank, plumbing, fuel pump, electrical components, and ignition system components. Additionally, the trainer includes vital elements such as thermal control switches, control valves, an air blower, and associated ducting, all crucial for the proper operation of the air conditioning system.

2.2 Standard Operation Procedure (SOP)

Standard Operating Procedures (SOPs) are crucial documents that outline the necessary steps to safely and effectively perform a specific task. In the context of the aircraft air conditioning system trainer model AS-43, SOPs are essential for ensuring consistent and secure practices during training sessions. These SOPs enhance safety and efficiency by providing clear instructions and guidelines for operating the trainer. By following the SOPs, users can perform tasks correctly and up to the required standards, thereby improving the overall quality of their work.

2.3 Hierarchy of Control (Safety Hierarchy)

The safety hierarchy proposed outlines a systematic approach to hazard control, particularly relevant to handling the AS-43 aircraft air conditioning system trainer. The hierarchy of control shown in Fig. 3 presents a preferred order of control methods, starting with elimination as the most effective and ending with personal protective equipment (PPE) as the least effective method.

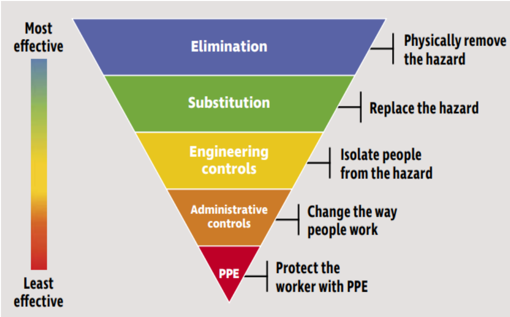

Fig. 2 - Hierarchy of control (NIOSH)

When handling the AS-43 trainer system, following the safety hierarchy pyramid is recommended. Proper implementation of the hierarchy enhances safety during training sessions and ensures the well-being of individuals interacting with the trainer system. Proposed Safety Hierarchy for handling AS-43 are as follow:

1. Every user (students and staff) must always comply with all the safety rules that have been outlined while in laboratory.
2. Refusal to comply with all the safety rules that have been outlined can result in being required to be fully responsible for any untoward incident while in the laboratory such as damage to the equipment used, injuries or accidents that occur while in the laboratory, etc.
3. It is compulsory to wear appropriate and safe clothing as outlined in the university dress code when in the laboratory.
4. Make sure the technician/lab assistant on duty are informed beforehand using the equipment.
5. Make sure you know the correct and safe method before using the necessary equipment. Please refer to the technician/lab assistant on duty at the laboratory.
6. Use the tools and safety clothing, personal protective equipment (PPE) that has been provided when using the necessary equipment.
7. Report immediately to the technician/lab assistant on duty in the event of any untoward incident such as equipment damage, injury, accident, electrical damage and so on.
8. After finished using all the necessary equipment, make sure that the work area has been packed and cleaned while the equipment used has been rearranged in the place that has been prepared.
9. Always ensure that all equipment power switches that have been used are turned off before leaving the laboratory or workshop.

2.4 Research Parameters

2.4.1 Temperature Change

Temperature is a fundamental measure of thermal energy in a substance and is crucial for assessing whether it is hot or cold. Common temperature scales include celsius (C) and fahrenheit (F), while thermodynamics applications often use absolute scales like kelvin (K) and rankine (R). To measure the temperature in an aircraft air-conditioning system, various instruments can be utilized, such as thermometers, resistance thermometers, thermocouples, thermistors, and digital display thermometers. These tools provide accurate temperature readings, enabling the control of the air-conditioning system to maintain a comfortable environment for passengers. The temperature control is essential not only for passenger comfort but also to ensure the safety and optimal functioning of the aircraft's systems and crew.

$$\Delta T = T_{high} - T_{low} \qquad (1)$$

When working with the AS-43 Aircraft Air-conditioning Trainer System, the most suitable tools for obtaining temperature measurements are thermocouples and thermistors. These devices are commonly used in air-conditioning systems and can accurately measure temperature in different environments.

Table 1 - Some of the most common thermocouples

Type	Common names	Temperature range (°C)
T	Copper-constantan (C/C)	-250 to 400
J	Iron-constantan (I/C)	-200 to 850
E	Nickel chromium-constantan or Chromel-constantan	-200 to 850
K	Nickel chromium-nickel aluminum or Chromel-alumel (C/A)	-180 to 1100
N	Nicrosil-nisil	0 to 1300
S	Platinum 10% rhodium-platinum	0 to 1500

R	Platinum 13% rhodium-platinum	0 to 1500
B	Platinum 30% rhodium-platinum 6% rhodium	0 to 1600

Thermocouples detect temperature by measuring the voltage generated between two different metal wires with varying temperatures, while thermistors sense temperature by measuring the resistance of a semiconductor material that changes with temperature. Both tools provide reliable temperature readings for the AS-43 system.

2.4.2 Pressure Difference

The pressure difference at the expansion valve is a critical parameter in the operation of the AS-43 ACS trainer. It refers to the variance in pressure between the high-pressure side, where refrigerant enters the valve from the compressor, and the low-pressure side, where refrigerant is released to the evaporator. This pressure difference is vital for controlling the flow of refrigerant and ensuring proper cooling within the air conditioning system. Measuring the pressure difference can be accomplished using a pressure gauge or other appropriate measuring devices. This measurement assists in diagnosing and troubleshooting any potential issues within the air conditioning system, enabling effective maintenance and operation.

$$\Delta P = P_{high} - P_{low} \qquad (2)$$

To calculate the pressure difference at the expansion valve, Equation 2 is utilized. The pressure difference (ΔP) is obtained by subtracting the pressure on the low-pressure side (P_low) from the pressure on the high-pressure side (P_high). This equation provides a straightforward method for quantifying the pressure difference, which is crucial for maintaining optimal performance and efficiency of the AS-43 ACS trainer.

The high-pressure side (P_high) of the expansion valve receives refrigerant from the compressor, while the low-pressure side (P_low) releases refrigerant to the evaporator. The pressure difference (ΔP) between these two sides regulates the refrigerant flow, ensuring that the appropriate pressure levels are maintained for effective cooling. Understanding and accurately measuring the pressure difference is essential for diagnosing any potential issues, troubleshooting problems, and ensuring the smooth operation of the air conditioning system in the AS-43 ACS trainer.

2.4.3 Relative Humidity

The relative humidity (RH) difference in the aircraft air conditioning system can be determined using the equation

$$RH = (Pw / Pws) \times 100 \qquad (3)$$

Where

Pw represents the water vapor pressure in the air.

Pws represents the saturation vapor pressure of water at the same temperature.

This equation establishes that relative humidity is the ratio of the amount of moisture in the air to the maximum amount it can hold at a specific temperature. Measuring the temperature and pressure of the air within the trainer system allows for the calculation of Pw and Pws, facilitating the determination of relative humidity. In this study, in order to track relative humidity, Q-Trak indoor air quality monitor 7575 is used. This device provides real-time data, logs information for analysis, and offers additional features such as dew point and wet bulb calculations.

Fig. 3 - Q-Trak indoor air quality monitor 7575

To maintain comfortable conditions within the aircraft air conditioning system, temperature and relative humidity levels must adhere to specific ranges. The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) recommends a dry bulb temperature of 20-23°C with a relative humidity of 50 ± 20% during winter, and a dry bulb temperature of 24-27°C with a relative humidity of 50 ± 20% during summer. Achieving these conditions requires the air conditioning system to adjust the air state to balance the varying loads between summer and winter. Monitoring and analyzing the relative humidity data obtained from the Q-Trak indoor air quality monitor 7575 assist in ensuring optimal performance, identifying potential issues, and maintaining the desired comfort levels within the aircraft air conditioning system.

2.4.4 Enthalpy

Enthalpy, also known as heat content, can be calculated for the AS-43 ACS trainer system using the following equation:

$$H = u + Pv \qquad (3.3)$$

Where
H is the enthalpy
u is the internal energy
P is the pressure
v is the volume

This equation is based on the first law of thermodynamics, which states that the energy of a closed system remains constant. The enthalpy system can be calculated by measuring the temperature and pressure of the system and using the specific heat capacity of the refrigerant. It's important to note that this equation is only valid for a closed system where the pressure and volume are constant. This equation can be applied to the AS-43 ACS trainer system by measuring the temperature and pressure of the refrigerant at the different stages of the cooling process, such as at the compressor, expansion valve, and evaporator. By using these measurements and the specific heat capacity of the refrigerant, the enthalpy of the trainer system can be calculated at each stage.

In the case of the AS-43 ACS trainer system, which uses a refrigerant to cool the air, the pressure and volume will change during the process of cooling. For this study, enthalpy can be obtained from P-h diagram according to the refrigerant used (R134a).

3. Result

From the research parameters, an experiment using the Aircraft Air Conditioning System Trainer Model AS-43 conducted and data tabulated as shown in Table 4.3.

Table 4.2 - Experimental data

	"Manual" Cool	"Auto" Cool
Pressure of flow in condenser, P_{HP} (bar)	10	9.5
Pressure of flow in evaporator, P_{BP} (bar)	2.8	2.3
Inlet temperature of condenser, T_0 (°C)	31.6	32.2
Outlet temperature of condenser, T_1 (°C)	38.0	36.6
Inlet temperature of evaporator, T_2 (°C)	24.5	20.7
Outlet temperature of evaporator, T_3 (°C)	36.4	37.3
Initial Relative Humidity, RH_1 (%)	42	42
Final Relative Humidity, RH_2 (%)	50	53

3.1.1 Temperature Change

By applying Equation (1),

Manual Cool

Temperature change of condenser, $\Delta T = T_1 - T_0$

ΔT = 38.0°C - 31.6°C

ΔT = 6.4°C

Temperature change of evaporator, $\Delta T = T_3 - T_2$

ΔT = 36.6°C - 24.5°C

ΔT = 12.1°C

Auto Cool

Temperature change of condenser, $\Delta T = T_1 - T_0$

ΔT = 36.6°C-32.2°C

ΔT = 4.4°C

Temperature change of evaporator, $\Delta T = T_3 - T_2$

ΔT = 37.3°C - 20.7°C

$\Delta T = 16.6°C$

3.1.2 Pressure Difference

By applying Equation (2),

Manual Cool

$\Delta P = P_C - P_E$

$\Delta P = 10$ bar - 2.8 bar

$\Delta P = 7.2$ bar

Auto Cool

$\Delta P = P_C - P_E$

$\Delta P = 9.5$ bar - 2.3 bar

$\Delta P = 7.2$ bar

3.1.3 Enthalpy

From P-h diagram R134a, enthalpy can be determined. Fig. 5 and Fig. 6 shows P-h diagrams for both Manual Cool and Auto Cool respectively.

Manual Cool

Fig. 5 shows the P-h diagram constructed based on the result of the experiment for Manual Cool.

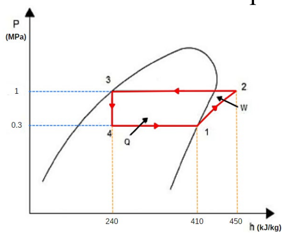

Fig. 4 - P-h Diagram for manual cool

From P-h diagram shown in **Fig. 5**, we obtained

$h_1 = 410\ kJ/kg\ ,\ h_2 = 450\ kJ/kg,\ h_3 = h_4 = 240\ kJ/\ kg$

Heat absorbed by the evaporator, $q_{evap} = h_1 - h_4$

$q_{evap} = 410 - 240$

$q_{evap} = 170\ kJ/kg$

Heat rejected by the condenser, $q_{cond} = h_2 - h_3$

$q_{cond} = 450 - 240$

$q_{cond} = 210\ kJ/kg$

Work done to drive the compressor, $w_{comp} = h_2 - h_1$

$w_{comp} = 450 - 410$

$w_{comp} = 40\ kJ/kg$

$$Coefficient\ of\ performance, COP = \frac{h_1 - h_4}{h_2 - h_1}$$

$$COP = \frac{410 - 240}{450 - 410} = 4.25$$

<u>Auto Cool</u>

Fig. 6 shows the P-h diagram constructed based on the result of the experiment for Auto Cool

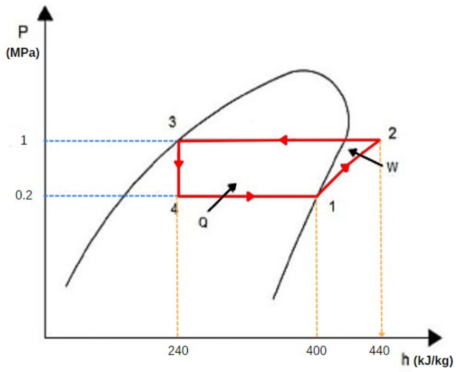

Fig. 5 - P-h diagram for auto cool

From P-h diagram shown in Fig. 6, we obtained
$h_1 = 400\ kJ/kg,\ h_2 = 440\ kJ/kg,\ h_3 = h_4 = 240\ kJ/\ kg$

Heat absorbed by the evaporator, $q_{evap} = h_1 - h_4$
$q_{evap} = 400 - 240$
$q_{evap} = 160\ kJ/kg$

Heat rejected by the condenser, $q_{cond} = h_2 - h_3$
$q_{cond} = 440 - 240$
$q_{cond} = 200\ kJ/kg$

Work done to drive the compressor, $w_{comp} = h_2 - h_1$
$w_{comp} = 440 - 400$
$w_{comp} = 40\ kJ/kg$

$$Coefficient\ of\ performance, COP = \frac{h_1 - h_4}{h_2 - h_1}$$

$$COP = \frac{400 - 240}{440 - 400} = 4.0$$

3.2 Discussion

The experiments conducted on the AS-43 air conditioning system trainer provide valuable insights into its performance in both "Manual" Cool and "Auto" Cool modes. The temperature change analysis reveals that the condenser effectively removes heat from the refrigerant in both modes, resulting in temperature drops of 6.4°C and 4.4°C for "Manual" Cool and "Auto" Cool modes, respectively. Additionally, the evaporator absorbs heat from the outside air, leading to temperature drops of 12.1°C and 16.6°C for "Manual" Cool and "Auto" Cool modes, respectively. These temperature changes demonstrate the efficiency of the system components in facilitating heat transfer and cooling.

The pressure measurements indicate that both "Manual" Cool and "Auto" Cool modes experience the same pressure difference (ΔP) of 7.2 bar. This suggests that the vapor compression cycle system undergoes similar pressure variations in both modes. The P-h diagrams provide further insights into the heat transfer within the system. The analysis reveals that the evaporator absorbs 170 kJ/kg and 160 kJ/kg of heat in "Manual" Cool and "Auto" Cool modes, respectively, while the condenser rejects 210 kJ/kg and 200 kJ/kg of heat in the respective modes. These values illustrate the thermal energy transfer within the system, with slightly higher heat absorption and rejection observed in the "Manual" Cool mode.

The coefficient of performance (COP) serves as a key parameter for assessing the efficiency of the vapor compression cycle system. The calculated COP for the "Auto" Cool mode is 4.0, while the COP for the "Manual" Cool mode is 4.25. These values represent the ratio of cooling effect to work input, with the "Manual" Cool mode exhibiting a slightly higher COP. Overall, these results demonstrate the effectiveness of the AS-43 air conditioning system trainer in both "Manual" Cool and "Auto" Cool modes, providing valuable insights for understanding and evaluating the system's performance.

4. Conclusion

In summary, the study was successful in identifying a SOP and safety hierarchy that are appropriate for aircraft air conditioning trainer systems. These guidelines will ensure the safe and effective operation and maintenance of the trainer system, minimizing potential risks for both students and faculty. Besides, the AS-43 trainer model has proven to be an effective educational tool for mechanical and aeronautical students. Its ability to illustrate the working principles of each system component and the complete air conditioning process of a light aircraft enhances students' understanding and knowledge of aircraft air conditioning systems. Through the study, the functioning and performance of the AS-43 trainer model have been comprehensively examined. The analysis of temperature, relative humidity, pressure, and enthalpy changes within the system during operation has provided valuable insights for the students regarding the physics and behavior of aircraft air conditioning systems.

In conclusion, AS-43 Aircraft Air Conditioning System Trainer was effective in demonstrating the vapor cycle air conditioning method. The safety hierarchy and SOP that were developed during the study will enhance the ways the trainer is handled and used. Students in mechanical and aeronautical engineering programs will benefit greatly from the proposed lab manual. the insights gained from this study will greatly contribute to the teaching and understanding of aircraft air conditioning systems, ensuring safe operations and enhancing the educational experience for mechanical and aeronautical engineering students.

4.1 Recommendation

For further improvement, modifications and improvement to the current study have been developed and addressed. Consequently, the following advice could be taken into account and inferred from this research. Firstly, AS-43 trainer should undergo periodic maintenance to secure its performance. This is to ensure that the trainer system can operate well with optimal performance and maintain the trainer's effectiveness and reliability over time. Besides, for future research, it is recommended to study on the long-term reliability and durability of aircraft air conditioning systems. It might be useful to identify the potential areas of improvement for a long-term performance.

Other than that, the trainer should be utilized more as a teaching and learning element or tool, offering practical experiments and trouble-shooting exercise. Students' understanding increases by the analysis of temperature, humidity, pressure, and enthalpy changes, which offers insightful information about aircraft air conditioning systems. For future use, a proposal of lab manual designated for experiment are beneficial to be parallel to this study. Also, the study's findings and recommendations will benefit the educational experience for students studying aeronautical and mechanical engineering by providing them with useful knowledge and skills that are in line with technological advancements in the field. Implementing the proposed SOPs and safety hierarchy for the AS-43 trainer system will ensure safe and effective operation, reducing risks and enhancing the training experience.

By considering these recommendations, the study of the AS-43 aircraft air conditioning system trainer will be further improved, offering an enhanced learning experience for students and contributing to advancements in the field of aircraft air conditioning systems.

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