A Novel Aircraft Air Conditioning System with a Sterilization Unit by Ultra-High-Temperature Air Stream

SUN Zhi[1], *SUN Jianhong*[2,1*], *CHEN Siyu*[1]

1. Key Laboratory of Aircraft Environment Control and Life Support, MIIT, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, P.R. China;

2. College of Civil Aviation/College of Flight, Nanjing University of Aeronautics and Astronautics, Nanjing 211106, P.R. China

(Received 10 March 2020; revised 5 July 2020; accepted 14 July 2020)

Abstract: An aircraft cabin is a narrow, closed-space environment. To keep the air quality in cabin healthy for passengers, especially during an epidemic such as SARS-CoV-2 (or 2019-nCoV) in 2020, a novel aircraft air conditioning system, called the ultra-high-temperature instantaneous sterilization air conditioning system (UHT-ACS), is proposed. Based on the proposed system, a simulation of the UHT-ACS is analysed in various flight states. In the UHT-ACS, the mixing air temperature of return and bleed air can reach temperature up to 148.8 ℃, which is high enough to kill bacilli and viruses in 2—8 s. The supply air temperature of the UHT-ACS in a mixing cavity is about 12 ℃ in cooling mode, both on the ground and in the air. The supply air temperature is about 42 ℃ in heating mode. Compared with the air conditioning systems (ACS) of traditional aircraft, the supply air temperatures of the UHT-ACS in the mixing cavity are in good agreement with those of a traditional ACS with 60% fresh air and 40% return air. Furthermore, the air temperature at the turbine outlet of the UHT-ACS is higher than that of a traditional ACS, which will help to reduce the risk of icing at the outlet. Therefore, the UHT-ACS can operate normally in various flight states.

Key words: air conditioning system (ACS) ; ultra-high-temperature instantaneous sterilization; ultra-high-temperature instantaneous sterilization air conditioning system (UHT-ACS); return air; 2019-nCoV

CLC number: V231.1 **Document code:** A **Article ID:** 1005-1120(2020)04-0646-09

0 Introduction

With the development of civil aviation, more and more people are choosing air transportation for mid- and long-range travel. In recent years, the number of civil aviation flights has increased significantly. During a flight, the health and safety of passengers is an important issue to be considered because they must stay in a small, enclosed cabin environment for long periods. Therefore, the aircraft air conditioning system is an important mechanism for providing a healthy air atmosphere for passengers. It achieves this by adjusting the parameters of the cabin environment, such as pressure, temperature and humidity.

To date, the spread of viruses has become more frequent and severe, such as SARS in 2003, H1N1 in 2009, Ebola and SARS-CoV-2 (or 2019-nCoV) in 2020[1-2]. The high infectivity and fatality rate of these viruses make people reluctant to take public transportation during an epidemic. With the most recent epidemic, airlines have had to cancel thousands of flights and all airline carriers are suffering deep financial losses. In flight, much of the infection risk comes from the mouths, noses and hands of passengers sitting close to one another. To decrease the risk, it becomes a matter of wearing ad-

*Corresponding author, E-mail address: jhsun@nuaa.edu.cn.

How to cite this article: SUN Zhi, SUN Jianhong, CHEN Siyu. A novel aircraft air conditioning system with a sterilization unit by ultra-high-temperature air stream[J]. Transactions of Nanjing University of Aeronautics and Astronautics, 2020, 37(4): 646-654.

http://dx.doi.org/10.16356/j.1005-1120.2020.04.015

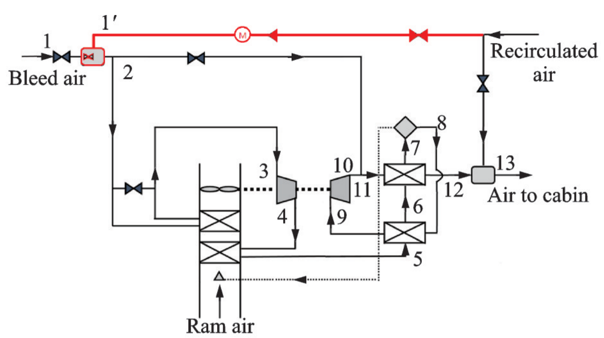
equate personal protective equipment, such as masks, protective cover, clothing and gloves, and refraining from eating and drinking for several hours. Therefore, the air quality in the cabin is related to the health and safety of passengers. How to defend passengers from infection during an epidemic becomes an urgent task for aircraft air conditioning systems (ACS).

The disinfection and sterilization of air conditioning systems have applied mainly to the architectural field[3-4]. Yanagi et al.[5] reported experimental results on the sterilization effect of ozone on microorganisms, including the "exposure intensity" for the required sterilization time. LYU et al.[6] studied the microwave sterilization of biological pollution in the central air conditioning systems of buildings and found that microwave radiation at a power of 900 W was ideal for reaching an effective sterilization temperature (50—59 ℃) within 5 min. Li et al.[7] found that the inner dust weight of air conditioning pipes was high and that microbial pollution was serious. TiO_2 was used as a photocatalyst purification mechanism for killing microorganisms on air duct surfaces in a timely manner. Shi et al.[8] developed a complete set of intelligent cleaning-sterilizing equipment for the ventilation ducts of an air-conditioned passenger train. However, the investigations of aircraft air conditioning systems have focused mainly on cooling and heating performance. Wang[9] and Shu et al.[10] simulated the performance of traditional aircraft air conditioning systems. Nan et al.[11] and Wu[12] analysed the recirculation systems on civil aircraft. Sun et al.[13-14] developed a Bayesian failure prognostics approach using airplane condition monitoring system (ACMS) data for the predictive maintenance of air ACS. They proposed a novel health indicator extraction method based on available sensor parameters for the health monitoring of the ACS on a legacy commercial aircraft model. The method can identify the ACS failure precursors in advance with the relative errors of less than 8%. The proposed method was validated on a single-aisle commercial aircraft, which was widely used for medium-haul routes. Tu et al.[15] provided a new method for the dynamic simulation of aircraft environmental control systems (ECS). The method was demonstrated by performing steady-state and dynamic analyses in dry and wet operating conditions. Jennions et al.[16] proposed a simulation framework called the Simscape environmental control system simulation under all conditions (SESAC). It simulated the health state indicating parameters at the subsystem and component levels under a wide range of aircraft operating scenarios. Tfaily et al.[17] presented an integration considering environmental control and ice protection systems, compared the multidisciplinary design optimization (MDO) results obtained with and without the considered air systems, and demonstrated the impact on optimal aircraft design. Li et al.[18] and Sun et al.[19] used failure mode and effects analysis (FMEA) and hierarchy multi-signal flow to diagnose faults in an aircraft ACS. Moreover, simulation of the transportation of passengers in an aircraft cabin is also an important topic. Liu et al.[20] explored the interpersonal exposure to exhaled droplets and droplet nuclei of two standing thermal manikins. He found a substantial increase in airborne exposure to droplet nuclei exhaled by the source manikin when a susceptible manikin is within about 1.5 m of the source manikin. Lin et al.[21] studied the transmission law of respiratory pathogens through the breath of sick passengers in an aircraft cabin to reduce the risk of infection by the numerical modelling of a Boeing 737 economy cabin. The susceptible-exposed-infectious (SEI) model was taken as an evaluation index for the risk of infection for other passengers. Jan et al.[22] studied the dependency between the type of air distribution system and indoor air quality in the cabin of a small transport aircraft. Three types of air distribution system were investigated by computational fluid dynamics (CFD). The results showed that the most stable air distribution was attained with a modified mixing air distribution system. Sun et al.[23] suggested an improved evaluation index called the predicted mean vote for fighter (PMV_F) to measure the thermal comfort in an aircraft cabin. The flow and temperature fields of the cabin were simulated. Farag et al.[24] studied a ventilation system with both underfloor displacement and personalized ventilation (PV) with GB injection in the aircraft cabin of the economy section of a Boeing 767 airplane during cruising. They also studied the protection of passengers by air curtains designed for different states. They found that an air curtain was effective for preventing the spread of GB, but of course this also increased the temperature and decreased thermal comfort inside the aircraft cabin.

In civil aircraft, recirculation air is used in ACSs. Although ACSs have high-efficiency particulate air (HEPA) filters, this is still a great threat to passengers' health during the epidemic, especially on long flights. To solve the problem, a new aircraft ACS is proposed in this paper. It uses an ultra-high-temperature instantaneous sterilization method. The method has been proven useful and effective under various conditions both on the ground and in flight.

1 Ultra-High-Temperature Instantaneous Sterilization Air Conditioning System

It is known that if temperature reaches 135—150 ℃, bacilli and viruses can be killed within 2—8 s[25]. Therefore, in order to sterilize and kill viruses in the return air of an ACS, a new system called the ultra-high-temperature instantaneous sterilization air conditioning system (UHT-ACS)[26] is described in this paper. The system schematic diagram is shown in Fig.1. Compared with a traditional ACS, a high-temperature sterilization recirculation subsystem pipeline is added in the UHT-ACS. The



1—Bleed air; 1′—Return air; 2—Mixing air; 3—Air inlet of compressor; 4—Air outlet of compressor; 5—Air outlet of the second heat exchanger; 6—Air inlet of condenser; 7—Air outlet of condenser; 8—Air outlet of water separator; 9—Air inlet of turbine; 10—Expansion air of turbine; 11—Air outlet of turbine; 12—Air inlet of mixing cavity; 13—Air to cabin from mixing cavity.

Fig.1 Ultra-high-temperature instantaneous sterilization air conditioning system

working principle of the UHT-ACS is that the recirculated air is mixed with high-temperature bleed air from the engine. Thus, the recirculated air temperature will become sufficiently high and virus and bacteria will be killed within one second in the high-temperature mixing cavity. Specifically, during an epidemic such as 2019-nCov, H1N1 or another influenza virus, the UHT-ACS can work. The traditional recirculation sub-pipeline is shut down, and a high-temperature sterilization recirculation sub-pipeline is opened. The recirculated air is transported to the high-temperature mixing cavity by a fan. Then, it is mixed with the high-temperature bleed air from the engine though an ejector in the mixing cavity. After mixing, the gas temperature is high enough to kill viruses and sterilize the air. The mixing air is cooled by the ACS. Then the temperature is adjusted to one that is suitable to supply to the cabin.

2 Calculation Model

2.1 Heat exchanger

The heat exchanger is the main heat transfer component in the system. High-temperature air enters the hot side and cold air enters the cold side. Its heat exchange equation is given by

$$(mC_p)_{\mathrm{w}}\mathrm{d}T_{\mathrm{w}} = Q_{\mathrm{m}}\mathrm{d}t\left[C_p(T_{\mathrm{hin}} - T_{\mathrm{hout}}) + i_{\mathrm{g}}(d_{\mathrm{in}} - d_{\mathrm{b}})\right] - \eta h_{\mathrm{wout}}A_{\mathrm{wout}}(T_{\mathrm{w}} - T_{\mathrm{cold}}) \tag{1}$$

$$T_{\mathrm{hout}} = T_{\mathrm{w}} + (T_{\mathrm{hin}} - T_{\mathrm{w}})\mathrm{e}^{-a_c} \tag{2}$$

$$a_c = \frac{\eta h_{\mathrm{win}}A_{\mathrm{win}}}{Q_{\mathrm{m}}C_p} \tag{3}$$

where m is the mass of the heat exchanger, C_p the specific heat of the fluid, i_{g} the phase transformation enthalpy, d the humidity ratio of the air, and h the convective heat transfer coefficient. The subscript "w" denotes the wall parameter of the heat exchanger, the subscript "win" denotes the inner wall parameter of the heat exchanger and the subscript "wout" denotes the outer wall parameter of the heat exchanger. In addition, the subscript "h" denotes hot fluid, the subscript "cold" denotes cold fluid, the subscript "in" denotes inlet and the subscript "out" denotes outlet.

The pressure loss of the heat exchanger consists of friction drag, additional pressure loss, and local pressure drop. The total pressure loss of the heat exchanger is

$$\Delta p = \Delta p' + \Delta p_{\mathrm{cf}} - \Delta p'' + \Delta p_{\mathrm{a}} \tag{4}$$

$$\Delta p = \frac{\omega^2 v'}{2}\left[(1-\sigma^2+K') + 2\left(\frac{v''}{v'}-1\right) + \frac{4fL}{d_{\mathrm{e}}}\frac{v_{\mathrm{m}}}{v'} - (1-\sigma^2-K'')\frac{v''}{v'} + \xi_{\mathrm{a}}\frac{v_{\mathrm{m}}}{v'}\right] \tag{5}$$

where $\Delta p'$ is the pressure loss inlet the core of the heat exchanger, $\Delta p''$ the pressure rise at the core outlet, Δp_{cf} the pressure loss in the core, and Δp_{a} the local pressure drop at the connection. Meanwhile, σ is the porosity of the heat exchanger, K' the pressure loss coefficient of the heat exchanger at the inlet, ω the mass flow rate, v' the specific volume, v_{m} the average of the specific volumes, f the flow coefficient of the core, d_e the equivalent diameter of the core, L the characteristic length of the core, K'' the pressure loss coefficient of the heat exchanger at the outlet, ξ the local pressure drop coefficient at the connection, and ν'' the average of the specific volumes at the core outlet.

2.2 Compressor

The compressor is an important component in the UHT-ACS. As the compressor is working, its parameters change rapidly and the thermal inertia is small; therefore, it can be considered as an approximately steady-state process. According to the adiabatic change process of the compressor, the equation of the model can be given by

$$m_1 = m_2 = \eta_{\mathrm{v}} \rho V/60 \tag{6}$$

$$\eta_{\mathrm{v}} = 0.94 - 0.085\left[\left(\frac{p_{\mathrm{c}}}{p_{\mathrm{e}}}\right)^{\frac{1}{N}} - 1\right] \tag{7}$$

$$V = \frac{i\pi D^2}{4} S \cdot n \tag{8}$$

$$h_{\mathrm{out}} = h_{\mathrm{in}} + w \tag{9}$$

$$w = \frac{N}{N-1}\frac{p_{\mathrm{e}}}{\rho}\left[\left(\frac{p_{\mathrm{c}}}{p_{\mathrm{e}}}\right)^{\frac{N-1}{N}} - 1\right] \tag{10}$$

where m_1 and m_2 are the mass flow rates in and out of the compressor, respectively; N is the index of polytropic compression, η_{v} the volume efficiency of the compressor, p_{c} the condensing pressure, p_{e} the evaporating pressure, V the volume of the compressor, w the work done by per kilogram of air in the compressor, h_{in} the enthalpy of the air at the compressor inlet, h_{out} the enthalpy of the air at the compressor outlet, i the number of compressor cavities, D the diameter of the compressor, S the number of compressor strokes, and n the rotational speed.

2.3 Turbine

In the ACS, the pressure and temperature of the air decrease sharply after expansion in the turbine. It becomes low-temperature air, which is used to cool the cabin. The flow, efficiency and speed characteristics are main performance characteristics of the turbine. Based on these characteristic curves, the model of the turbine is established, as follows[20]

$$T_{\mathrm{ex}} = T_{\mathrm{in}}[1 - \eta_{\mathrm{t}}(1 - \pi_{\mathrm{t}}^{-0.286})] \tag{11}$$

$$P_{\mathrm{t}} = \eta_{\mathrm{m}}\eta_{\mathrm{t}} q_{\mathrm{ml}} C_p T_{\mathrm{in}}(1 - \pi_{\mathrm{t}}^{-0.286}) \tag{12}$$

$$\eta_{\mathrm{t}} = f_{\mathrm{t}}(x_0, Re, k, \lambda_u) \tag{13}$$

where η_{t} is the adiabatic efficiency, π_{t} the expansion ratio, η_{m} the torque efficiency, x_0 the speed ratio, Re the Reynolds number of the gas in the turbine, k the isentropic exponent and, λ_u the velocity coefficient of the air.

2.4 Water separator

The water separator is used to remove the liquid phase water from the air. The temperature of the air passing through the water separator is basically unchanged. The water separation efficiency generally changes little for a given water separator. Therefore, it can be considered as a constant. Therefore, the pressure loss and humidity of air through the water separator can be given by

$$\Delta p_{\mathrm{w}} = \xi \frac{\rho v^2}{2} \tag{14}$$

$$d = d_0(1 - \eta_{\mathrm{w}}) \tag{15}$$

where η_{w} is the water separation efficiency (here, it is 0.9) and ξ the drag coefficient (here, it is 0.8).

3 Results and Analysis

According to the previous simulation model, the ACS is analysed. Here, steady-state cooling with a traditional ACS is taken as an example. The ACS is taken is in a steady flight state with a flight altitude of 6.1 km, flight speed of 158 m/s and ambient air temperature of −25 ℃[10]. The simulation results are shown in Table 1. Compared with the experiment and computational data, it is found that the calculation results in this paper are in good agreement with Ref.[10].

The ultra-high-temperature instantaneous sterilization (UHT) system is built according to the system schematic diagram shown in Fig.1. Four typical cases are used for calculation and comparison with the traditional ACS. Cases 1 and 2 are the cases on the ground in summer and winter, respectively. Cases 3 and 4 are at the cruising altitude in summer and winter, respectively. The specific detailed parameters are shown in Table 2.

According to Aviation Industry Standard HB 7489-2014, the temperature in the cabin is usually kept at 24 ℃ during flight. On hot days, the air temperature supplied to the cabin is 10—12 ℃. The upper limit is 15 ℃. On cold days, the maximum air temperature supplied to the cabin shall not exceed 50 ℃. Therefore, the set temperature of the air supplied to the cabin for refrigeration is 12 ℃ and the set temperature for heating is 42 ℃ in the ACS. The temperature of the return air is also 24 ℃, the same as the cabin temperature. In the novel UHT system, in order to achieve the high temperature (135—150 ℃) for instantaneous sterilization, the flow ratio of fresh air to return air is set as 60∶40 [12]. Thus, the temperature of the mixing air can reach 148.8 ℃, which is high enough to kill viruses almost instantaneously.

Table 1 Temperature and pressure of ACS simulation compared with experimental ones

Parameter	Result in Ref.[10]	Experimental result[10]	Calculation result
Mass flow rate / (kg•s^{-1})	0.303	0.302	0.302
Temperature of inlet compressor /℃	23.9	25	23.9
Temperature of outlet compressor /℃	58.5	59.8	61.3
Pressure of outlet compressor / kPa	218 849	219 474	219 493
Temperature of inlet water separator /℃	24.4	27.1	26.9

Table 2 Parameters of ACS in calculation

Parameter		Case 1 Altitude of 0 km in summer	Case 2 Altitude of 0 km in winter	Case 3 Altitude of 9.45 km in summer	Case 4 Altitude of 12 km in winter
Bleed air	Mass flow rate / (kg•s^{-1})	0.329	0.328	0.330	0.248
	Temperature /℃	232	232	232	232
	Humidity / (g•kg^{-1})	19	0.1	2	0
Ram air	Mass flow rate / (kg•s^{-1})	0.745	0.584	0.327	0.327
	Temperature /℃	26.4	−40	−8.9	−52.3
	Humidity / (g•kg^{-1})	19	0	2	0
	Pressure / kPa	101.3	101.3	28.8	19.4

In hot weather on the ground, the pressure and temperature change at various nodes by a traditional ACS and the UHT-ACS is shown in Fig.2. The temperatures at various component nodes are shown in Table 3. It can be seen that the air flow mass rate increases owing to the mixing of return air and bleed air in the UHT-ACS. The pressure in the working process of the UHT-ACS is higher than that of the traditional ACS. The temperature at the mixing air inlet of the ACS decreases to 148.8 ℃. The air temperature change trend is similar to that of the traditional ACS. After ACS, the temperature of air in the mixing cavity, which is supplied to the cabin, is 12.4 ℃. This is in the same region as the traditional ACS. Therefore, the UHT-ACS can meet the cooling demand of the aircraft in hot weather on the ground.

The simulation results of a traditional ACS and the UHT-ACS in cold weather, on the ground, are shown in Fig. 3. The temperature of each component node is shown in Table 3. It can be seen that

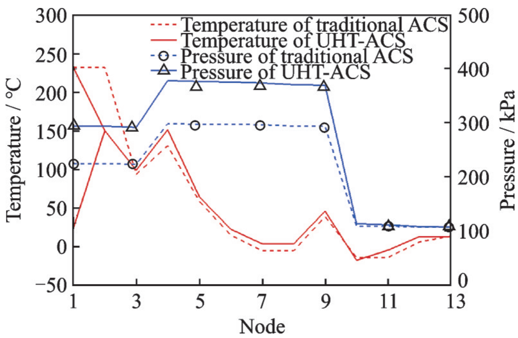


Fig.2 Pressure and temperature curves of different systems in hot weather on ground

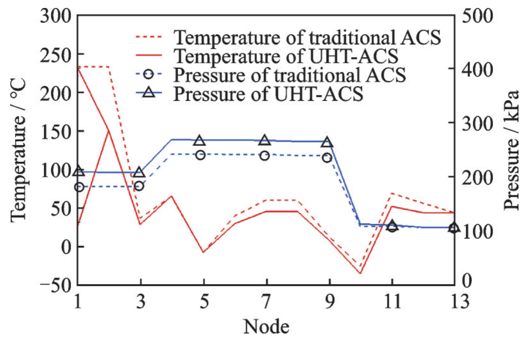


Fig.3 Pressure and temperature curves of different systems in cold weather on ground

Table 3 Temperature at different nodes in traditional ACS and UHT-ACS ℃

Node	Case 1		Case 2		Case 3		Case 4	
	Traditional	UHT	Traditional	UHT	Traditional	UHT	Traditional	UHT
Bleed air N_1	232.0	232.0	232.0	232.0	232.0	232.0	232.0	232.0
Mixing air N_2	232.0	148.8	232.0	148.8	232.0	148.8	232.0	148.8
Inlet compressor N_3	93.4	98.8	35.5	27.4	167.9	129.7	37.0	34.8
Out compressor N_4	130.6	150.8	63.7	64.1	219.9	186.8	68.0	72.7
Out second HX N_5	57.7	63.7	−8.9	−8.8	62.4	49.8	−16.2	−14.8
Inlet condenser N_6	14.2	21.7	38.6	28.2	14.7	19.8	36.2	26.1
Out water separate N_8	−5.7	2.7	59.0	44.0	−7.0	6.2	58.6	43.6
Inlet turbine N_9	38.6	45.4	11.6	7.3	41.6	36.7	6.3	2.9
Out turbine N_{11}	−14.8	−5.4	67.7	50.7	−16.9	0.4	68.2	51.2
Mixing cavity N_{13}	12.4	12.4	42.4	42.3	12.4	12.1	42.0	42.0

the pressure in the UHT-ACS is slightly higher than that in the traditional ACS. After ACS treatment, the air temperature in the mixing cavity of the traditional ACS is 42.4 ℃ , whereas that in the UHT-ACS is 42.3 ℃. These are both consistent with the set supply air temperature of 42 ℃; therefore, the UHT-ACS can meet the heating demand of the aircraft in cold weather.

The simulation results of a traditional ACS and the UHT-ACS in hot weather, at an altitude of 9.45 km, are shown in Fig.4. The temperature of

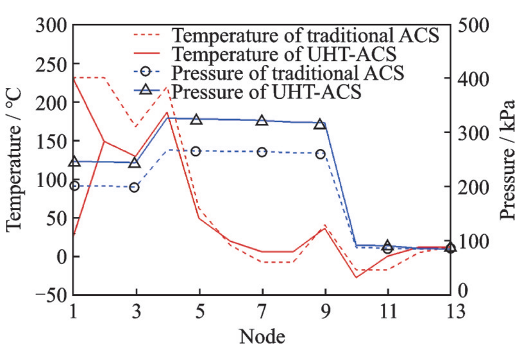


Fig.4 Pressure and temperature curves of different systems in hot weather at an altitude of 9.45 km

each component node is shown in Table 3. By comparison, it can be seen that the pressure in the system at high altitude is less than it is on the ground. This is caused by the low-pressure environment at high altitude. After treatment by the traditional ACS, the air temperature in the mixing cavity is 12.4 ℃ and that of the UHT-ACS is 12.1 ℃. They are all consistent with the set supply air temperature of 12 ℃. Therefore, the UHT-ACS can meet the refrigeration requirements of the aircraft during flight in hot weather.

The simulation results of a traditional ACS and the UHT-ACS in cold weather, at altitude of 12 km, are shown in Fig. 5. The temperature at each component node is shown in Table 3. It can be seen that the air temperature in the mixing cavity of the traditional ACS and that in the UHT-ACS are both 42.0 ℃. This is consistent with the set supply air temperature of 42 ℃. Therefore, the UHT-ACS and the traditional ACS can both be used for heating the cabin during flight in cold weather.

Comparing the outlet temperatures of the turbine in the refrigeration process, it is found that in the ground case the outlet temperature of the turbine of the traditional ACS is −14.8 ℃, whereas that of the UHT-ACS is −5.4 ℃. At the high-altitude case, the outlet temperature of the turbine if the traditional ACS is −16.9 ℃, whereas that with the UHT-ACS is 0.4 ℃. The higher turbine outlet temperature of the UHT-ACS helps to reduce the risk of icing at the turbine outlet. Therefore, the UHT-ACS is conducive to the normal operation of the system.

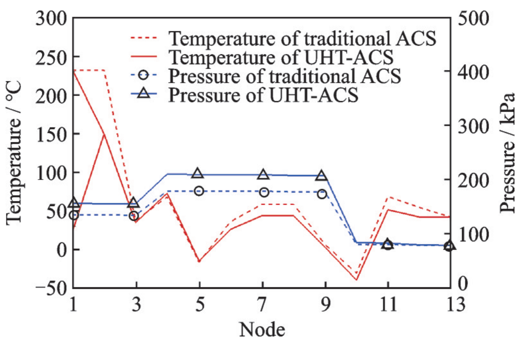


Fig.5 Pressure and temperature curves of different systems in cold weather at altitude of 12 km

4 Conclusions

A new ACS called the UHT-ACS was proposed in this paper. The system was calculated by simulation under various conditions. The results of the supply air temperature in the mixing cavity were in good agreement with the required set values in all cases. The main conclusions are as follows:

(1) In the UHT-ACS, the temperature of the mixing air can reach 148.8 ℃, which is sufficient to kill bacilli and viruses. Since the novel system simply modifies the existing air flow route, it does not complicate the design of air-conditioning system.

(2) The UHT-ACS can operate normally under various weather conditions while the aircraft is on the ground and during flight.

(3) The air temperature outlet the turbine of the UHT-ACS is higher than that of a traditional ACS, which helps to reduce the risk of icing at the turbine outlet.

This paper presents a novel aircraft sterilization air conditioning system, called the UHT-ACS. The UHT-ACS was compared with a traditional ACS in various steady conditions by simulation. The feasibility of the UHT-ACS was proven. However, the unsteady simulation of an entire flight is needed to analyse the burden and cost of the aircraft with the UHT-ACS. Therefore, the burden and cost of the aircraft with UHT-ACS, and the influence of the relevant parameters on the UHT-ACS should be studied in future works.

References

[1] JIANG S, XIA S, YING T, et al. A novel coronavirus (2019-nCoV) causing pneumonia-associated respiratory syndrome[J]. Cellular & Molecular Immunology, 2020, 17: 554-561.

[2] LI X, WANG W, ZHAO X, et al. Transmission dynamics and evolutionary history of 2019-nCoV[J]. Journal of Medical Virology, 2020, 92: 501-511.

[3] ZHANG Yinping, ZHAO Bin, CHENG Tongbao, et al. Overview of disinfection methods of biologic pollution in HVAC system[J]. Heating, Ventilating and Air Conditioning, 2003, 33(U06): 41-46. (in Chinese)

[4] LIU Zhuqing, CHANG Jingjing, ZHANG Dongliang. Observation on the effect of fresh air system combined with air purification and disinfection machine on the air disinfection of dialysis room[J]. Chinese Journal of Disinfection, 2017, 34(11): 89-90. (in Chinese)

[5] YANAGI U, IKEDA N. Research on the behavior and control of microbial contamination in an air conditioning system: Part3 fundamental experiments on the sterilization performance of ozone[J]. Journal of Environmental Engineering, 2008, 73: 1197-1200.

[6] LYU Yang, HU Guangyao, LIANG Jingyi, et al. Study on microwave sterilization technology of humidifier in central air conditioning system[J]. Building and Environment, 2019, 160: 106220.

[7] LI H X, LI B N, GENG G, et al. Detection and analysis of microbial contamination in central air conditioning system of a university[J]. Advanced Materials Research, 2012, 610/611/612/613: 661-664.

[8] SHI Hongsheng, LEI Xuejun, ZHAO Yalin, et al. Research and development of intelligent cleaning-sterilizing equipments for central air conditioning ventilation duct of railway passenger car[J]. China Railway Science, 2011, 32(5): 140-144. (in Chinese)

[9] WANG Guangwen. Study of ram air energy consumption for air conditioning based on simulation[J]. Civil

Aircraft Design and Research, 2015(3): 22-25. (in Chinese)

[10] SHU Yi, LI Yanjun, CAO Yuyuan, et al. Modeling and simulation on aircraft air conditioning system[J]. Aeronautical Computing Technique, 2019(4): 72-75. (in Chinese)

[11] NAN Guopeng, SUN Xuede. Analysis of the recirculation impact to aircraft air conditioning performances[J]. Civil Aircraft Design and Research, 2012(4): 48-51. (in Chinese)

[12] WU Dan. Flow simulation of recirculation system on civil aircraft[J]. Civil Aircraft Design and Research, 2017, 125(2): 131-134. (in Chinese)

[13] SUN Jianzhong, WANG Fangyuan, NING Shungang. Aircraft air conditioning system health state estimation and prediction for predictive maintenance[J]. Chinese Journal of Aeronautics, 2020, 33(3): 947-955.

[14] SUN Jianzhong, LI Chaoyi, LIU Cui. A data-driven health indicator extraction method for aircraft air conditioning system health monitoring[J]. Chinese Journal of Aeronautics, 2019, 32(2): 409-416.

[15] TU Y, LIN G. Dynamic simulation of humid air environmental control system[C]//Proceedings of the 40th International Conference on Environmental Systems. [S.l.]: AIAA,2010.

[16] JENNIONS I, ALI F, MIGUEZ M E, et al. Simulation of an aircraft environmental control system[J]. Applied Thermal Engineering, 2020, 172: 114925.

[17] TFAILY A, KOKKOLARAS M. Integrating air systems in aircraft multidisciplinary design optimization[C]//Proceedings of 2018 Multidisciplinary Analysis and Optimization Conference. [S.l.]:[s.n.], 2018.

[18] LI Bingyue, SUN Jianhong, LIU Haigang, et al. Fault diagnosis and simulation of aircraft air conditioning system based on FMEA[J]. Journal of Vibration Measurement and Diagnosis, 2017, 37(3): 588-595.

[19] SUN Zhi, SUN Jianhong, LI Bingyue, et al. Fault diagnosis of aircraft air conditioning system based on hierarchy multi-signal flow[J]. Journal of Vibration Measurement and Diagnosis, 2018, 38(1): 196-201. (in Chinese)

[20] LIU L, LI Y, NIELSEN P V, et al. Short-range airborne transmission of expiratory droplets between two people[J]. Indoor Air, 2017, 27(2): 452-462.

[21] LIN Jiaquan, SUN Fengshan, LI Yachong. Numerical simulation of spread and infection risk of respiratory pathogens in the aircraft cabin[J]. Journal of System Simulation, 2019, 31(8): 1541-1547. (in Chinese)

[22] JAN F, MIROSLAV J. Impact of air distribution system on quality of ventilation in small aircraft cabin[J]. Building and Environment, 2013, 69: 171-182.

[23] SUN Zhi, SUN Jianhong, ZHAO Ming, et al. Analysis of thermal comfort in aircraft cockpit based on the modified PMV index[J]. Acta Aeronautica et Astrinautica Sinica, 2015, 36(3): 819-826. (in Chinese)

[24] FARAG A M, KHALIL E, HASSAN M. Numerical study of decreasing the spread of sarin (GB) in an air-conditioned aircraft cabin[C]//Proceedings of International Energy Conversion Engineering Conference. Salt Lake City, USA: AIAA, 2016.

[25] ZHANG Youliang, ZHAO Gang, FU Jiansheng. Feature and electrical control of tubular UHT (ultra-high temperature) sterilizing[J]. Packaging and Food Engineering, 2005, 23(5): 20-23. (in Chinese)

[26] SUN Jianhong, SUN Zhi. The high temperature instantaneous sterilization air conditioning system of aircraft and its method: CN202010129659.2[P]. 2020-06-12. (in Chinese)

Acknowledgements This work was supported by the Project Funded by the Priority Academic Program Development of Jiangsu Higher Education Institutions (PAPD) and the Foundation of Jiangsu Postdoctoral (No. 2019K126).

Authors Dr. **SUN Zhi** received the Ph.D. degree in Man-Machine and Environmental Engineering from Nanjing University of Aeronautics and Astronautics (NUAA) in 2018. In May 2018, he joined the College of Aerospace Engineering, NUAA, Nanjing, China. He is engaged in the research of computational fluid dynamics (CFD), thermal management of aircraft, helicopter lifesaving technology and so on.

Prof. **SUN Jianhong** received his B.S. and M.S. degrees in Aerodynamics from NUAA in1989 and1996, respectively. He received Ph. D. degree in Mechanical Engineering from Hong Kong University of Science & Technology in 2001. His research interests are focused on environmental fluid mechanics and aircraft environment control and life support.

Author contributions Dr. **SUN Zhi** complied the models, conducted the analysis, interpreted the results and wrote the manuscript. Prof. **SUN Jianhong** designed the study, revised and modified the manuscript. Ms. **CHEN Siyu** contributed to the model and the discussion of the study. All authors commented on the manuscript draft and approved the submission.

Competing interests The authors declare no competing interests.

(Production Editor: ZHANG Tong)

一种高温瞬时灭菌民用飞机空调系统

孙　智[1]，孙建红[2,1*]，陈思宇[1]

（1.南京航空航天大学飞行器环境控制与生命保障工信部重点实验室，南京 210016，中国；2.南京航空航天大学民航学院/飞行学院，南京 211106，中国）

摘要：飞机座舱是一个狭小的封闭空间环境，空调系统的供气品质关系着舱室乘员的健康。为了保障新型冠状病毒（2019-nCoV）疫情期间飞机座舱内乘员的健康安全，本文提出了一种新型的高温瞬时灭菌空调系统（Ultra-high-temperature instanteous sterilization air conditioning system，UHT-ACS）。在此基础上，对不同飞行状态下的UHT-ACS系统和传统飞机空调系统（Air conditioning system，ACS）进行了仿真计算。通过分析可知，UHT-ACS系统中的座舱再循环空气与高温高压的发动机引气相混合后，混合空气温度可达148.8 ℃，从而实现高温瞬时灭菌的目的。当热天UHT-ACS系统进行制冷时，系统送风温度为12 ℃左右，当冷天UHT-ACS系统进行加热时，系统送风温度为42 ℃左右，满足飞机空调系统的要求。通过与传统飞机空调系统的对比可知，当系统新风量为60%，再循环空气为40%时，本文提出的新型UHT-ACS系统供气温度与传统飞机空调系统供气温度一致，并且UHT-ACS系统的涡轮出口空气温度要高于传统飞机空调系统，这有助于降低涡轮出口结冰的风险。因此，本文提出的新型UHT-ACS系统可满足飞机不同飞行状态下的空气调节需求，能够为飞机座舱提供安全供气。

关键词：飞机空调系统；高温瞬时灭菌；高温瞬时灭菌空调系统；再循环空气；新型冠状病毒