Matching Calculation of Performance Parameters based on Advanced Aircraft Environment Control System

Xuejuan Zhao [1, a], Yang Zhang [2, b]

[1]School of Aeronautic Science Engineering, Beihang University, Beijing 100191, China

[2]China Nuclear Power Engineering Co. Ltd, Beijing 100840, China

[a]xjzhao@buaa.edu.cn, [b]zhangyang@cnpe.cc

Abstract

This paper proposed an advanced airborne system which combined the traditional environment control system with Rankine cycle system to solve the 'thermal problem' faced by modern aircraft. In view of the difficulties and complexities in the traditional matching calculation method, this paper established the enthalpy parameter model which made the enthalpy variables be the state parameters instead of the temperature variables. This paper finished the matching calculation of performance parameters for the proposed advanced aircraft environment control system based on enthalpy parameter model by MATLAB programming platform which could work under different operating points well.

Keywords

Environment control system, matching calculation, enthalpy, MATLAB.

1. Introduction

The core part of the airborne environment control system is the refrigeration system, which is used to secure the safety and comfort, guarantee the normal operation of electronic equipment. At present, air turbine refrigeration technology is widely applied to the advanced civil aircraft and military aircraft [1-2]. Furthermore, this technology derives from the high-temperature bleed air of the airborne engine. It is generally accepted that there is much thermal energy contained in the bleed air and the high-temperature bleed air has to be cooled preliminary by ram air. This traditional method not only causes the waste of the heat energy, but also threatens the stealth performance seriously due to the use of ram air. This paper proposed an advanced airborne environment control system which combined with the Rankine cycle system [3] to solve the 'thermal problem' faced by modern aircraft mentioned above. This combined system can refrigerate the bleed air by recycling the heat energy which can not only improve the level of thermal energy but also guarantee the excellent performance of modern aircraft owning to decrease the use of ram air. To sum up, the proposed environment control system is an effective way to solve the 'thermal problem'. As matching calculation of performance parameters was the essential factor to the system design work, this paper mainly discussed the matching method, modeling process and calculation results by enthalpy-matched method.

2. Advanced Aircraft Environment Control System

As mentioned above, the so-called advanced aircraft environment control system is a combined system with Rankine cycle system and traditional environment control system. As shown in the left side of Fig.1, the Rankine cycle system is constituted by four main components, evaporator, power turbine, condenser and working fluid pump. And a typical simplified aircraft environment control system is shown in the right part of Fig.1. This two systems are combined by the evaporator which is used for working fluid to absorb heat energy from the high-temperature bleed air in environment control system to finish the evaporation process. And then the steam with both high pressure and temperature leave the evaporator to come into the power turbine to expand until the pressure decreases to the condensation state. At the same time, the power turbine will operate to drive the attached generator. In that case, we can see that this advanced aircraft environment control system could not only greatly refrigerate the bleed air and ensure the stealth performance of aircraft, but also convert heat into electrical energy which could provide power for airborne equipment.

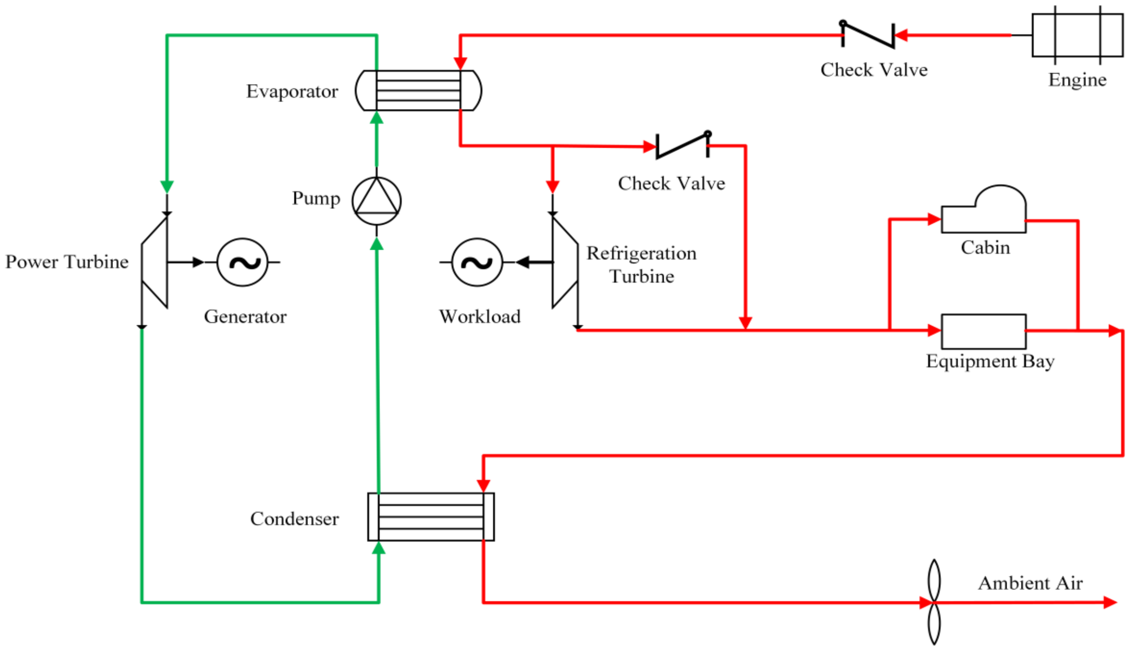

Fig. 1 Operation flowchart of the combined system

3. Matching Calculation of Performance Parameters

3.1 Introduction of Enthalpy-Matched Method

As the aircraft environment control system usually operate under the wet conditions, we have to repeat the iteration method constantly to judge that if the inlet and outlet state of heat exchanger are saturated or not to select the corresponding calculation method for the next matching process.So we can see that the phase transformation make the matching calculation process become complicated and inaccurate[4], and the traditional matching method related to the temperature efficiency model is not suitable any more. As a state parameter, enthalpy is used to describe the dynamic characteristics in the two-phase heat exchange process, which is a comprehensive description for the temperature and humidity ratio of moist air.The mathematical model of enthalpy-matched method is following:

The enthalpy calculation of moist air:

$$h = 1.01t + 0.001d(2501 + 1.85t) \tag{1}$$

The empirical formula of temperature and saturated pressure of moist air:

$$p_{sat} = 0.61 \times 10^{\frac{7.45t}{235+t}} \tag{2}$$

The saturated humidity ratio of moist air:

$$d_{sat} = 622\frac{p_{sat}}{p - p_{sat}} \tag{3}$$

The conversion relation of enthalpy and temperature:

$$h = f\,(t, d, d_{sat}) \tag{4}$$

To sum up, enthalpy is a function of temperature and humidity ratio and we can achieve the conversion between the enthalpy and the temperature under any state point of moist air but not only the saturated state by using the formulas above.

3.2 Modeling of Advanced Aircraft Environment Control System

As shown in Fig.2, the advanced aircraft environment control system is constituted by evaporator, regenerator,water condenser, separator, refrigeration turbines and condenser for working fluid. It is necessary to point out that we use a generator here instead of the compressor and fan to be the workload for turbines because of their unsatisfied performance especially in the boundary of flight envelope.

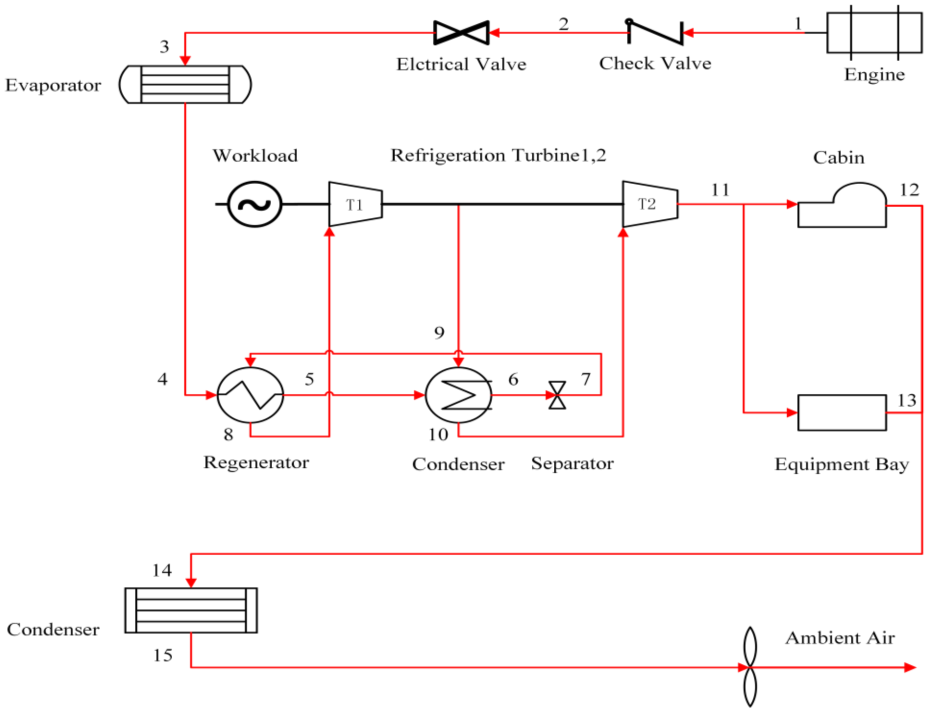

Fig. 2 Operation flowchart of the advanced aircraft environment control system

The mathematical model of the environment control system shown above is following:
the thermal efficiency and thermal equilibrium of the regenerator:

$$\eta_{re} = \frac{h4 - h5}{h4 - h7} \tag{5}$$

$$q_{m1} \cdot (h4 - h5) = q_{m2} \cdot (h8 - h7) \tag{6}$$

the thermal efficiency and thermal equilibrium of the condenser for water:

$$\eta_{con} = \frac{h5 - h6}{h5 - h9} \tag{7}$$

$$q_{m1} \cdot (h5 - h6) = q_{m2} \cdot (h10 - h9) \tag{8}$$

the calculation model of the high pressure water separator:

$$h6 = h7, t6 = t7, \quad d6 = d7 \tag{9}$$

the enthalpy-matched model of the first stage turbine marked as T1:

$$\frac{h9 + 273.15c_p}{h8 + 273.15c_p} = 1 - \eta_{T1}(1 - \frac{1}{\varepsilon_{T1}^{0.286}}) \tag{10}$$

the enthalpy-matched model of the second stage turbine marked as T2:

$$\frac{h11 + 273.15c_p}{h10 + 273.15c_p} = 1 - \eta_{T2}(1 - \frac{1}{\varepsilon_{T2}^{0.286}}) \tag{11}$$

the expansion ratio relation of the two-stage turbines:

$$\varepsilon_{T2} \cdot 101 + \Delta p_{9-10} = \frac{P8}{\varepsilon_{T1}} \tag{12}$$

the power ratio of the two-stage turbines marked as γ:

$$(h10 - h11) = \gamma(h8 - h9) \tag{13}$$

3.3 Analysis of matching calculation for system performance parameters

According to engineering experience, we suppose that the inlet and outlet state point of environmental control system are known as shown in Table.1. To simplify the total calculation process,we could make point 4 as the inlet point and point 11 as the outlet point.

To make Eq.(1)~(13) simultaneous and closed, it is necessary to suppose that the state of moist air leaving out of the water condenser marked as point 6 is saturated.

3.4 Results of matching calculation for system performance parameters

Based on the closed enthalpy-matched mathematical model, we can acquire the matching results of the advanced environment control system by programming in MATLAB.

Table 1 Calculation parameters of the inlet point and outlet point

Point	Mass flow/ kg/s	Temperature/ ℃	Pressure/ kpa	Humidity ratio/ g/kg
4	0.278	100	606	22
11	0.278	4	101	<5

Table 2 Matching results of system performance parameters

Point	Pressure/ kpa	Enthalpy/ kJ/kg	Temperature/ ℃	Humidity ratio/ g/kg
4	606	160.00	100.00	22
5	596	99.75	42.57	22
6	586	36.95	26.98	3.8
7	581	36.95	26.98	3.8
8	576	97.29	83.96	4.7
9	313	27.20	15.16	4.7
10	303	90.00	76.81	4.7
11	101	15.83	4.00	4.7

Table 3 Matching results of design parameters for system components

Parameters	Value	Parameters	Value
η_{re}	0.49	ε_{T1}	1.84
η_{con}	0.87	ε_{T2}	3.01
η_{T1}	0.65	γ	1.06
η_{T2}	0.75	—	—

4. Conclusion

This paper established the enthalpy-matched model for the advanced aircraft environment control system and made the physical concept clear, the calculation process simplified and accurate.

We can use the enthalpy parameter model and the iteration method to match the system performance parameters easily under different operation conditions by programming in Matlab.

As shown in Table.2, the humidity ratio of the air for cabin and equipment bay is 4.7g/kg, which is up to the drying requirement in environment control system.And the design parameters in Table.3 provide the basis for further study.

References

[1] J.Wang, Y.J.Liu, S.J.Dong. Advanced technolories of integrated aircraft utility ststem and ECS, Journal of Beihang University, vol.29 (2003)No.11,p.959-963. (In Chinese)

[2] R.Z.Shou, H.S.He: Aircraft Environment Control(Beihang University Press,China 2006), p.166-171. (In Chinese)

[3] X.Feng, J.Xu, M.N.Wang. The advantage of the organic rankine system in the low –temperature heat recovery, Energy Conservation Technology, vol.28 (2010) No.5, p.387-391. (In Chinese)

[4] X.J.Zhang, F.Li, C.X.Yang. Calculating method for matching enthalpy parameter of four wheel boost refrigeration system for civil aircraft, Journal of Beihang University, vol.36 (2010) No.9, p.1009-1012. (In Chinese)