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Research on the Influence of Atmospheric Temperature on Working Capacity of Afterburner

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Abstract: *Certain type of hybrid afterburner turbofan engine is studied to research the influence of atmospheric temperature on working capacity of afterburner. First, the temperature characteristics above the airport of the area is obtained based on the flight height envelope of aircraft and in combination with the trial flight temperature data of certain airport over the previous years. Second, in combination with the characteristics of research object and by reference of working capacity model of afterburner based on empirical formula, the trial flight data that the engine switches on in afterburner with the same test point and different temperatures, is adopted to research the change of the working capacity of afterburner at different temperatures. The research results indicate that: The temperature at the altitude of more than 13km basically keeps unchanged, so, the influence of temperature may not be considered; With the reduction of external temperature at the altitude of less than 12km, the light-on and stable working capacity of afterburner tend to decline; Therefore, in the trial flight process, the influence of temperature in different seasons on test results shall be considered at the afterburner light-on boundary of less than 12km.*

Keywords: *atmospheric temperature, afterburner, working capacity, empirical formula and comprehensive parameters*

1. Introduction

With the development of current international situation, more and more severe requirements are proposed to the combat operation capability of weapon equipment. Almost all modern fighter planes adopt the afterburner which can significantly enhance and improve the airplane performance and expand the flight envelope [1]. Currently, the operating quality identification and the trial flight of turbofan engine afterburner are appraised and verified within the given height speed boundary. The empirical qualitative appraisal concerning the smooth light-on for three times at the boundary test point is often adopted, but lacks the support of quantitative index, which may result in great deviation of boundary obtained via test. For example, the atmospheric condition in different seasons changes greatly, and then the intake air temperature and pressure of engine change accordingly, which triggers the difference of engine state and results in the discrepancy of test results of the same test point in different seasons. Especially when the high-altitude small airspeed boundary is close to the capacity boundary of afterburner, the difference of engine status may directly result in the totally different test results. The working capacity of afterburner is modeled based on the trial flight data to research the influence of atmospheric temperature on the working capacity of turbofan engine afterburner, to provide support for subsequently specifying the afterburner performance base number.

2. Research methods

The engine afterburner has different import parameters in distinct atmospheric environmental conditions. Different atmospheric temperature would inevitably affect the import parameters of engine afterburner, thus affecting the afterburner working capacity. Therefore, the high and low temperature shall be considered in the trial flight appraisal, and the afterburner working capacity model could address such problem. First, the characteristics of atmospheric temperature are analyzed, then the model is adopted for auxiliary evaluation based on the trial flight data to research the influence of afterburner light-on and stable working capacity.

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2.1. Characteristics of atmospheric temperature

Based on the physical characteristics of the atmosphere and the altitude, the atmospheric layer is internationally divided into the troposphere, stratosphere, mesosphere, thermosphere and mesosphere. Currently, the airport's flight envelope is distributed at bottom of troposphere and stratosphere. The troposphere generally refers to the altitude from the ground to 11km, and the atmospheric temperature gradually declines with the increase of altitude, namely the air temperature decreases by 6.5°C when every 1,000m altitude increases on average; The stratosphere refers to the altitude from the top of the troposphere to about 50km. At the bottom of stratosphere (altitude of less than 30km), the atmospheric temperature almost keeps unchanged, and the average temperature reaches - 56.5°C. The change rule of standard atmospheric temperature at different heights is shown in figure 1 [2].

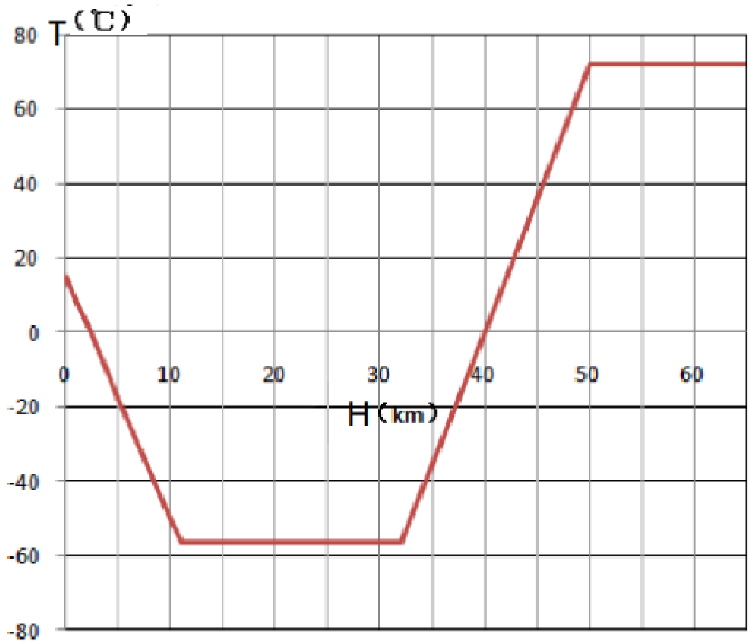

Figure 1: Change rule of standard atmospheric temperature at different heights

Based on the statistical analysis results of temperature data of atmospheric environment above certain airport over the previous years, the characteristic diagram of atmospheric environment temperature above the airport can be obtained, and the following conclusions could be drawn based on figure 2:

1) There are two transition altitudes. When the altitude is more than 11.0km~14.0km, the outer atmospheric temperature basically keeps unchanged, and such transition altitude would gradually increase with the rising of airport temperature; When the altitude is between 1.5km~5.0km and 11.0km~14.0km, with the rising of altitude, the outer atmospheric temperature gradually reduces apparently. The reduction scope of outer atmospheric temperature is between 6.5°C~8.0°C when the altitude increases by 1km. When the altitude is less than 1.5km~5.0km, with the rising of altitude, the outer atmospheric temperature gradually reduces, but the reduction rate is slightly lower. The reduction scope of outer atmospheric temperature is between 2.0°C~6.5°C when the altitude increases by 1km;

2) At the altitude of more than 11.0km~14.0km, the temperature of external environment basically keeps unchanged, and the scope of temperature is - 70°C~-58°C. With the increase of atmospheric temperature in airport, such transition altitude continuously increases, for example, the transition altitude reaches 11.0km, 12.5km and 14.0km, respectively, when the airport temperature is 8°C~12°C, 18°C~28°C and 28°C~40°C.

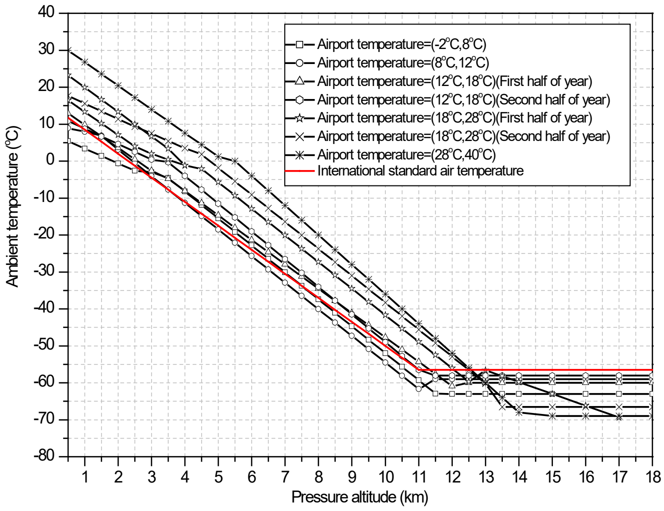

Figure 2: Characteristic diagram of ambient temperature above certain airport

Therefore, the influence of different atmospheric temperature on the afterburner working capacity at the altitude of less than 11km is mainly researched in this paper.

2.2 Afterburner working capacity model

First, the influence of each pneumatic thermodynamic parameter of afterburner inlet is analyzed theoretically, then, the comprehensive parameters are constructed according to the empirical function concluded from component tests and in combination with inlet condition parameters of internal and external culvert of afterburner to establish the afterburner working capacity model composed of comprehensive parameters and gas-oil ratio.

2.2.1 Calculation of comprehensive parameters

The key factors of afterburner ignition and stable working capacity are reliant on the matching of the afterburner fuel quantity and afterburner inlet aerodynamic parameter. In the condition of the confirmed gas-oil ratio, the stability is a function mainly related to the afterburner inlet aerodynamic parameter. The inlet aerodynamic parameters mainly cover the total pressure, total temperature, airflow velocity, etc. and their influence on afterburner working capacity mainly implicates: 1) With the reduction of total pressure of inlet, the ignition performance and flame stability go bad and the combustion efficiency reduces. Upon the reduction of afterburner inlet pressure and temperature, the afterburner stable working area shrinks with the change of excess air coefficient from small value to large value, and the figure 3 offers the afterburner flameout characteristics. 2) The inlet temperature of engine afterburner is mainly affected by two aspects: First, the total temperature of afterburner inlet reduces and the initial evaporation rate of fuel oil is slow. Moreover, upon the combustion in the downstream backflow area of V-shaped flame stabilizer, the fuel oil in the backflow area touches the flame front, and the fuel oil further absorbs heat after evaporation, resulting in the stable flame; Second, after the total temperature of afterburner inlet is excessively high, the Mach number keeps unchanged, but the air intake speed increases with the rising of temperature, which generates adverse impact on the performance of afterburner. 3) To obtain good combustion stability and ignition performance, the Mach number at afterburner flame stabilizer inlet shall be within the scope of 0.2~0.3 in general. The increase of average airflow velocity of afterburner inlet is bad for the afterburner ignition.

Stable combustion theory indicates that only within certain clinical value (turbulent flame propagation velocity) for the gas mixture flow velocity, the flame can keep stable when the aerodynamic parameter of incoming flow and gas-oil ratio keep unchanged. The theoretical model of stable combustion is mostly established based on that. Domestic and foreign scholars have been engaged in lots of research on such aspect. In the 1950s, Dezubay, after researching the flame stability characteristics of blunt body flame stabilizer, found the correlation of bluff body's flameout gas-oil ratio, bluff body inlet pressure, temperature and speed, and proposed the Dezubay parameter upon the research of the flameout boundary of disc blunt body[3]. King proposed the King correlation parameters in the V-shaped stabilizer flameout boundary test[4]. Lefebvre constructed the stable combustion model of afterburner via test and theoretical analysis, and gave the flameout condition [5]. Those theoretical

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characteristics are greatly difficult to be applied in engineering due to the restriction of test conditions.

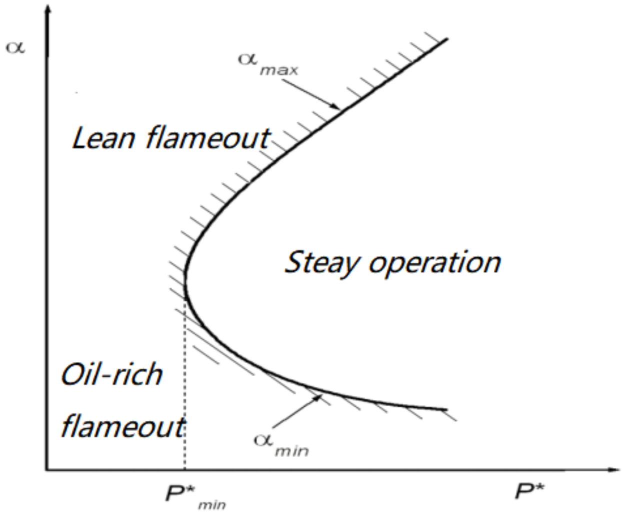

Figure 3: Flameout characteristics of afterburner

Based on the fundamental characteristics of influence of incoming flow parameters on afterburner working: the lower pressure is corresponding to more difficult afterburner organization combustion, the higher flow velocity is corresponding to more adverse combustion, the increase of temperature is conducive to combustion, etc. By reference of empirical function, some scholars propose to construction of comprehensive parameters based on the afterburner incoming flow parameters K:

$$K = \frac{L * P * T}{V} \tag{1}$$

Wherein: L refers to the structural parameter of afterburner, and L refers to the groove width of main stabilizer. Among the structural parameters of main stabilizer, based on the stable flame mechanism of bluff body, the groove width of bluff body determines its working stability and combustion chamber efficiency.

2.2.2 Gas-oil ratio

The afterburner ignition working process shows that the flow rate of fuel oil atomized by the nozzle in afterburner area I is the oil supply upon afterburner ignition. Therefore, the fuel oil flow of nozzle can be calculated to obtain the oil supply upon the afterburner ignition. The following empirical formula is adopted for calculation:

$$Wf = Fn * \sqrt{\Delta Pf} * 0.775 \tag{2}$$

Wherein: the unit of Wf is L/h;

Fn could be measured in test.

The gas-oil ratio FAR could be obtained based on the ratio of the afterburner ignition fuel quantity and afterburner inlet gas.

3. Research objects and calculation results

Certain type of afterburner turbofan engine is researched and adopts the mixed inlet-type afterburner. The comprehensive parameters of afterburner K are finally defined by reference of empirical function in literature and in combination with the characteristics of research objects:

$$K = B_6 \frac{L * P_6 * T_6}{V_6} + B_{16} \frac{L * P_{16} * T_{16}}{V_{16}} \tag{3}$$

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Wherein: B_6 aerodynamic parameter coefficient of internal culvert

B_{16} aerodynamic parameter coefficient of external culvert;

B_6, B_{16} can be obtained via the ratio of internal and external culvert flow rate of engine.

The trial flight data of such engine from the middle to maximum afterburner light-on process at a certain test point and at different temperature conditions are adopted to calculate its comprehensive parameters K and gas-oil ratio FAR, with the calculation results shown in Table 1 (dimensionless processing of data).

Table 1: Parameters and calculation results of afterburner light-on test point

S/N	H_P	V_i	T_1	K	FAR
1	0.98	0.996	-1.01	17.04792	0.002199
2	0.999	1.001	-0.986	17.38084	0.00241
3	1.003	0.976	-0.762	17.71096	0.002459
4	1.002	0.996	-0.729	18.61533	0.002533
5	1.001	0.984	-0.713	18.83183	0.002447
6	1.001	0.991	-0.618	19.14774	0.002692
7	0.999	0.982	-0.618	19.81513	0.002248
8	0.993	0.995	-0.607	19.65386	0.002275
9	1.003	0.999	-0.607	20.4879	0.002229
10	0.998	1.003	-0.544	21.13859	0.002226
11	1.006	0.996	-0.541	23.47947	0.002228

The above table shows that with the rising of temperature, the comprehensive parameters K tend to increase monotonously. The test point in working capacity model is distributed in the following figure. Figure 4 shows that, at such test point, the comprehensive parameters K and gas-oil FAR ratio at different temperature present monotonous change regularity. At the same altitude and speed, with the ring of temperature, the comprehensive parameters K gradually increases, which indicates that strong afterburner light-on and stable working capacity conforms to actual trial flight and theoretical analysis results [6,7].

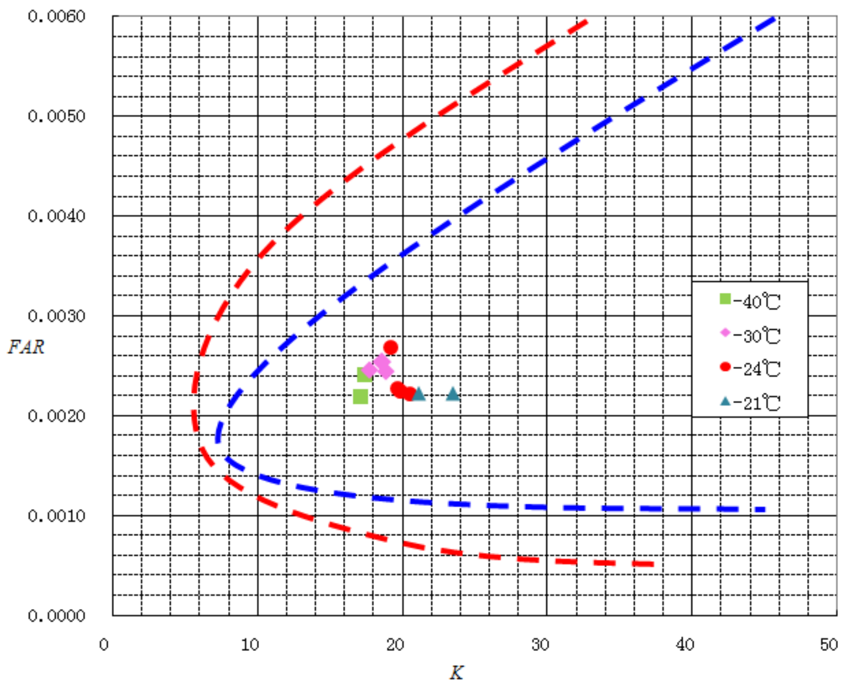

Figure 4: 2D data chart of afterburner working capacity at different temperatures

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4. Conclusion and prospect

The following concludes could be drawn via analysis and research:

1) With the reduction of external temperature, the light-on and stable working capacity of afterburner tend to decline;

2) The change characteristics of atmospheric temperature above the airport at different heights are as below: There are two transition altitudes. When the atmospheric temperature increases, the transition altitude continuously increases, and the temperature at the altitude of more than 13km basically keeps unchanged;

3) In the afterburner working quality trial flight process, the influence of temperature in different seasons on the test results shall be considered at the altitude of 5~12km, while the influence of temperature may not be considered temporarily at the altitude of 13km and above;

4) At the equal altitude and speed, new machine and performance attenuation engine present different afterburner inlet parameters. The afterburner working capacity model could be adopted for auxiliary evaluation subsequently, and can be expanded to 4D boundary of superimposed atmospheric temperature and engine attenuation on the basis of traditional afterburner light-on and stable working boundary defined with height and speed.

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