Research on An Adaptive Optimization Method of Anti-tank Missile in Plateau Environment

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Abstract. By analyzing the atmospheric elements of the plateau environment, the main factors affecting the dynamic characteristics of the missile are identified. From the analysis of the frequency domain characteristics of guided missiles and the guidance system parameters, we study the problem of the altitude adaptation of missiles. Comprehensive economy, adaptability, reliability and other factors were proposed to improve the dynamic characteristics of the missile's monomer under high altitude environment. The simulation results show that the method used in this paper can effectively improve the stability of the guidance system at the plateau, and the improved missile performance can basically meet the requirements of the plateau.

1. Introduction

During the trial test of a certain type of anti-tank missile in the plateau, some missiles dropped after launch. This type of anti-tank missile was mainly used in low-altitude plain environmental conditions at the beginning of design. In order to study the mechanism of the occurrence of land-drop and instability of this type of missile under the condition of high altitude, the problem of missile adaptability in high altitude environment was solved. The author considers this type of missile to be adapted to the plateau in terms of reliability, economy, and applicability.

Looking at the literature, we can see that some scholars have proposed a nonlinear method to solve missile ballistic problems[1]. Some researchers started from the conditions of the plateau environment and analyzed in detail the mechanism of the impact of the high-cold environment on missiles, and proposed a simple solution[2][3]. Several of these researchers started with correcting the network to solve the problem better, but the ability to solve complex situations is not enough[4][5]. Based on the above research, this paper starts with the dynamic characteristics of the plateau environment missiles, and analyzes the impact of altitude changes on the dynamic characteristics of missiles to design an improved solution with better reliability, economy, and applicability. Through simulation tests, the improved program meets operational requirements at different altitudes.

2. Plateau environment analysis

The main influencing factors of missile performance on the plateau environment are sound velocity, air density, gravitational acceleration, atmospheric pressure, oxygen content, temperature, and sunshine intensity[6]. The quantitative analysis of the impact of the air density on the dynamic characteristics of the missile is used to obtain the variation of each factor with altitude.
At sea level, temperature $T_0$, static pressure $P_0$ are $T_0 = 288.1667(K), P_0 = 101314.628(N/m^2)$.

At an altitude, according to the standard atmospheric model, the highland area of China is located in the first interval, that is, $z \leq 11000m$.

$$T_a = T_0 - (0.006499708)z(K) \quad (1)$$

$$P_a = P_0(1-2.255692257 \times 10^{-5} z)^{5.2561}(N/m^2) \quad (2)$$

In this interval, the density and sound velocity of the ambient atmosphere are given by the following formula:

$$\rho_a = \frac{P_a}{RT_a} (kg/m^3) \quad (3)$$

$$V_a = 20.037673 \sqrt{T_a}(m/s) \quad (4)$$

$R$ is the gas constant $(286.992360/N-mK)$. It should be noted that the speed of sound $V_a$ can also be obtained from the following relationship:

$$V_a = kRT \quad (5)$$

$k$ is the specific heat ratio of gas (The specific heat ratio of air is 1:4), $R$ is the gas constant, $T$ is the absolute temperature of the standard atmosphere, $T_a$ is the ambient atmospheric temperature at the altitude $z$, $P_a$ is the atmospheric pressure at altitude $z$, $\rho_a$ is the ambient atmospheric density at the altitude $z$, $V_a$ is the speed of sound at altitude $z$. Through simulation, we can get the curve of each element with altitude, as shown in Figure 1.

**Figure 1.** Changes in atmospheric characteristics at different altitudes

As can be seen from Figure 1, the greatest differences between atmospheric characteristics of the plateau and the plains are temperature, air density, and static pressure. However, due to the hardware characteristics of the missile, atmospheric pressure and temperature have little impact on the dynamic performance of the missile. Therefore, we mainly analyze the impact of air density changes on the dynamic performance of the missile.

3. Control system principle
The guided missile equipment of the modified missile is guided by the three-point guidance law. In the three-point guidance, it is necessary to constantly manipulate the missile so that it is located between the target tracker and the target. The three-point guidance method involves ground trackers, missiles, and targets. The combination of various functional modules shown in Figure 2.

Figure 2. Diagram of guidance link

According to the composition shown in Figure 2, missile-controlled flight trajectories can be constructed. In order to analyze the dynamic characteristics of missiles, a missile mathematical model was established. Due to the missile's axisymmetric layout, only the pitch direction is modeled and analyzed. After simplification and introduction of the kinetic coefficients, while ignoring some minor conditions, such as wash delay, etc., a simplified form of the longitudinal channel equations can be obtained[7].

\[
\begin{align*}
\dot{\vartheta} + a_{23} \dot{\vartheta} + a_{24} \vartheta &= -a_{25} \delta_z \\
\dot{\vartheta} - a_{24} \vartheta &= a_{35} \delta_z \\
\dot{\vartheta} - \vartheta - \alpha &= 0
\end{align*}
\]

(6)

\(a_{ij}\) is the Pitch motion coefficient, \(\vartheta, \vartheta, \alpha\) are respectively the pitch angle, the ball inclination angle and the angle of attack, in rad. Pulling the above equation can get the transfer function:

\[
W_K^\vartheta (s) = \frac{\dot{\vartheta}(s)}{\delta_z(s)} = \frac{-a_{25} s - a_{24} a_{34}}{s^2 + (a_{22} + a_{34}) s + a_{22} a_{34} + a_{24}}
\]

\[
W_K^\vartheta (s) = \frac{\dot{\vartheta}(s)}{\delta_z(s)} = \frac{-a_{25} a_{34}}{s^2 + (a_{22} + a_{34}) s + a_{22} a_{34} + a_{24}}
\]

\[
W_K^\alpha (s) = \frac{\alpha(s)}{\delta_z(s)} = \frac{-a_{25}}{s^2 + (a_{22} + a_{34}) s + a_{22} a_{34} + a_{24}}
\]

\[
s^2 + (a_{22} + a_{34}) s + a_{22} a_{34} + a_{24} = 0
\]

(7)

(8)

From Equation (7), the characteristic equation of each transfer function is Equation (8), with similar system characteristics. Among them, the coefficient \(a_{22}\) indicates the aerodynamic damping of the missile, \(a_{24}\) indicates the steady state of the missile, \(a_{25}\) indicates the efficiency of the elevator, and \(a_{34}\) indicates the angular deviation of the tangential rotation of the ballistic tangent caused by the angular deviation of the unit. Their expressions are:
\[ a_{22} = \frac{m^*}{m} \frac{qSb_A}{b_A} \frac{b_A}{V} \]  

\[ a_{24} = \frac{m^*}{m} \frac{qSb_A}{J_z} \]  

\[ a_{25} = \frac{m^*}{m} \frac{qSb_A}{J_z} \]  

\[ a_{34} = \frac{c^*}{m} \frac{qS + P}{mV} \]  

\( q \) is the flow pressure \( (q = \frac{1}{2} \rho V^2) \) and positive correlation with air density. Therefore, dynamic pressure determines the change law of the dynamic coefficient. It can be known from the characteristic equation that the missile's transfer coefficient decreases as the altitude increases. It shows that the control efficiency of the steering gear to the missile decreases with the elevation, and the maneuverability of the missile decreases. The transfer function of the system control object changes, resulting in instability of the control system.

4. Control system altitude adaptability improvement

The addition of autopilot to the original control system is an effective way to improve the dynamic performance of the system, but it is not feasible to consider issues such as cost and redesign. Without changing the hardware, changing the control commands in the control box has low cost and high reliability. According to the components of the control system, at an altitude of 4,000 meters, the open loop gain of the pilot loop is:

\[ G_k(s) = [W_c(s)W_D(s) + G(s)]W_0^\rho(s)W_f(s) \]  

Bring in related parameters:

\[ G_k(s) = \frac{0.0037s^3 + 1430.4s^2 + 3152s + 76.49}{s^3(0.05s + 1)(0.045s + 1)(0.022s + 1)(s^2 + 1.93s + 121.13)} \]  

From this we can get the open-loop Bode diagram of the original system, as shown in Figure 3.
From figure 3, the open-loop system p=0, the phase-frequency curve crosses the -180° line. According to the stability criterion of the logarithmic phase frequency characteristics, the closed-loop instability of the original control system in the plateau environment can be known. At the same time, during the flight of the missile, the turbulence is larger, the number of times is greater, the stability is not good, and the system adjustment time is too long and the response is slow. Therefore, corrections must be made through the corrective network to ensure that the dynamic characteristics of the system and the attitude of the plain remain stable at high altitudes. The design steps are as follows:

a) Open-loop frequency domain indicators such as slope and height of the lowest frequency band, open-loop cut-off frequency, and stability margin are converted from the required performance indicators (stabilization accuracy, adjustment time, and overshoot) of the missile.

b) Use the tool Sisotool of Matlab to adjust the open loop type and gain. Constantly try to make adjustments to change the shape of the high-frequency band in the open-loop Bird map to meet the requirements for stability, rapidity, and others (such as resistance to high-frequency interference).

c) Integrate correction network parameters for various time periods to obtain a suitable correction network function.

According to the flight characteristics of the missile, adjustments need to be made in two stages. The first stage is the limitation of the additional angle of attack on the adjustment instructions in the early period of the ballistics, reducing the system oscillation during the disturbance stage and ensuring a stable flight path. The second paragraph is the stability trajectory, the normal rotation speed does not need to carry on the big adjustment, the overload has reduced, returned to normal, therefore no longer limits the additional angle of attack. Through Sisotool try to figure out the best PD correction network parameters, get the time 3s when the PD correction network is shown by equation (15), and the open-loop system correction is shown in figure 4. Compared with figure 3, it can be seen that the system tends to be stable and the adjustment time and response speed are improved.

\[
C=0.00012975 \times \frac{1+51s}{1+0.66s}
\]

(15)

![Figure 4. Corrected system dynamic characteristic diagram](image)

In the same way, the corrected network parameters of each time period during which the missile is launched to hit the target can be found. After the integration, it can be found that the correction network of the entire process is a time-varying variable coefficient lead correction network.
\[ G_\tau = J_t \frac{is + 1}{js + 1} \]  \hspace{1cm} (16)

Where \( J_t \) is the gain function changes with time. The \( i \) and \( j \) satisfy equation (17)

\[ j = \frac{1}{\omega_n \sqrt{ij}} \]  \hspace{1cm} (17)

Through this network ballistic simulation, as shown in figure 5, when the missile is flying at high altitude, the closed loop system re-adjusts the re-filling instructions and adjustment instructions in the control law, and the flight trajectory tends to be flat to the line of sight and does not diverge.

![Altitudinal trajectory flight curve at 4000m altitude after adjustment](image)

Figure 5. Adjust the vertical surface ballistic flight curve at 4000m above sea level

5. Conclusion

Through the analysis of the flight characteristics of the plateau missiles, taking the plateau 4000m as an example, the original control system was adapted to the plateau. The simulation results prove the feasibility of the improved flight control law of the missile plateau, which makes the high-altitude combat performance of this type of missile more significant.

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