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Research on the Integrated Design of Missile Guidance Control Considering the Angle of Attack Constraint

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Abstract: *The integrated guidance and control design of missile considering the attack angle constraint can effectively improve the guidance accuracy and damage effect of the missile, which has become one of the hot spots in current research. In this paper, we review the problem of integrated guidance and control design of missile considering attack angle constraint. First, the steps to construct the ensemble model are described. Second, combining with the fact that modern control theory has been successfully applied to the design of missile weapon systems, the integrated design approach for missile guidance and control in recent years is summarized and summarized in this paper. Finally, the analysis and discussion of the problems and trends that need to be addressed in the integrated design of missile guidance and control can break through the constraints of traditional missile design concepts and methods and serve as a reference for the development of a new generation of missiles.*

Keywords: *attack angle constraint; missile; dynamic model; integrated guidance and control*

1. Introduction

In modern warfare, because the missile has the remarkable characteristics of high power, high precision, long range and strong penetration ability, it is a "killer app" for winning wars [1]. Missile weapon systems are complex systems armed with various advanced technologies, of which the guidance system and control system are an important part of the missile system. In recent years, the rapid development of missile guidance and control system related technologies has attracted the attention of various military powers, and has become a hot spot in the research of new weapons and equipment, reflecting important application prospects.

Traditional missile guidance systems and control system designs are designed with guidance and control loops separately [2]. Although this design method is feasible in engineering, it is necessary to repeatedly adjust the parameters when integrating the two circuits, which not only causes the repeatability of the design, but also does not necessarily ensure the overall performance of the system is optimal, which is not conducive to giving full play to the overall performance of the missile guidance system and control system. Especially after the missile enters the terminal guidance section, the coupling characteristics of the guidance system and control system of the missile are more prominent, which can easily lead to problems such as increased off-target and even instability of the projectile body.

In order to effectively improve the missile guidance control performance and actively respond to the great challenges of modern warfare, Williams et al. [3] first proposed the concept of Integrated Guidance and Control (IGC) in the 80s of the 20th century, and the guidance and control integration integrates the guidance system and control system, which fully considers the coupling characteristics between the guidance system and the control system, making the missile design more reasonable. It is also conducive to enhancing the combat effectiveness of missiles [4]. In the process of target strike, in order to achieve a better damage effect, the missile should also hit the target at a certain attack angle on the basis of meeting the requirements of strike accuracy. Therefore, considering the attack angle constraint in the integrated design of guidance and control is of great significance for the improvement of missile combat capability.

2. Igc Model Considering Angle of Attack Constrain

1) Based on the selected three-dimensional space, the missile and the target are treated as particles, and the relative motion relationship between the missile and the target is analyzed, and the relative motion relationship of the projectile is shown in Figure 1.

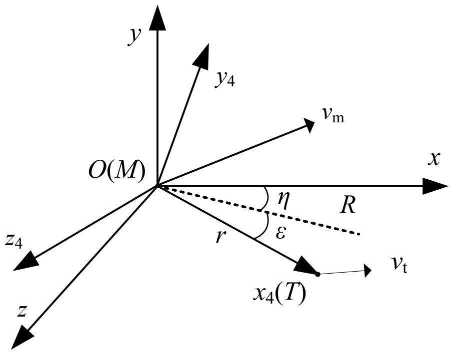

Figure 1: Relative motion relationship of projectiles.

In the figure, $Oxyz$ and $Ox_4y_4z_4$ are the inertial coordinate system and line-of-sight coordinate system, are the relative distance of the projectile, and indicate the eyesight inclination and line-of-sight declination of the projectile, and the missile and target speed. a_{mx_4} , a_{my_4} , a_{mz_4} and a_{tx_4} , a_{ty_4} , a_{tz_4} respectively, the acceleration components of the missile and the target on the three axes of the line-of-sight coordinate system. According to the relative motion relationship of the projectile in Figure 1, the relative motion model of the missile and target in three-dimensional space can be described [5].

$$\begin{cases} R - R\dot{\varepsilon}^2 - R\dot{\eta}^2\cos^2\varepsilon = a_{tx_4} - a_{mx_4} \\ 2\dot{R}\dot{\varepsilon} + R\ddot{\varepsilon} + R\dot{\eta}^2\sin\varepsilon\cos\varepsilon = a_{ty_4} - a_{my_4} \\ -R\ddot{\eta}\cos\varepsilon - 2\dot{R}\dot{\eta}\cos\varepsilon + 2\,\mathrm{R}\,\dot{\varepsilon}\dot{\eta}\sin\varepsilon = a_{tz_4} - a_{mz_4} \end{cases} \tag{1}$$

2) According to the missile dynamics equation, a missile dynamics model is established.

$$\begin{cases} \dot{\alpha} = -\omega_x\tan\beta\cos\alpha + \omega_y\tan\beta\sin\alpha + \omega_{\mathrm{z}} - \dfrac{C_y^{\alpha}\alpha QS - mg\cos\theta_m}{mv_m\cos\beta} + d_\alpha \\ \dot{\beta} = \omega_x\sin\alpha + \omega_y\cos\alpha + \dfrac{C_z^{\beta}\beta QS}{mv_m} + d_\beta \\ \dot{\gamma} = \omega_x - \omega_y\tan\theta\cos\gamma + \omega_{\mathrm{z}}\tan\theta\sin\gamma + d_\gamma \\ \dot{\omega}_x = \dfrac{(m_x^{\alpha}\alpha + m_x^{\beta}\beta + m_x^{\delta_x}\delta_x)QSL}{J_x} + \dfrac{J_y - J_z}{J_x}\omega_y\omega_z + d_{\omega_x} \\ \dot{\omega}_y = \dfrac{(m_y^{\beta}\beta + m_y^{\delta_y}\delta_y)QSL}{J_y} + \dfrac{J_z - J_x}{J_y}\omega_z\omega_x + d_{\omega_y} \\ \dot{\omega}_z = \dfrac{(m_z^{\alpha}\alpha + m_z^{\delta_z}\delta_z)QSL}{J_z} + \dfrac{J_x - J_y}{J_z}\omega_x\omega_y + d_{\omega_z} \end{cases} \tag{2}$$

where, m is the mass of the missile, g is the acceleration of gravity, θ_m 、 θ 、 α 、 β 、 γ is the missile trajectory inclination, pitch angle, angle of attack, side slip angle and roll angle, J_x 、 J_y 、 J_z is the moment of inertia in the roll, yaw and pitch directions, ω_x 、 ω_y 、 ω_z are roll, yaw and pitch angular velocities, m_x^{α} 、 m_{y}^{α} is the derivative of the roll and pitch moment coefficients to α , m_x^{β} 、 m_{y}^{β} are derivatives of the rolling and yaw moment coefficient pairs respectively, $m_x^{\delta_x}$, $m_y^{\delta_y}$ and $m_z^{\delta_z}$ are derivatives of roll, yaw, and pitch moment coefficients for δ_x , δ_y and δ_z , d_α , d_β , d_γ , d_{ω_x} , d_{ω_y} , d_{ω_z} is the external perturbation and modeling error.

3)The attack angle is defined as the angle between the guidance terminal missile velocity vector and the target velocity vector, taking the longitudinal plane as an example, because the attack angle θ_d has a one-to-one correspondence with the terminal line of sight angle $\varepsilon(t_f)$, the attack angle constraint problem can be transformed into the terminal line of sight constraint problem.

Combined with the missile dynamics model and kinematic equation, select the state variable $\left[\sigma(t) \quad \dot{\sigma}(t) \quad \alpha \quad \omega_z\right]^T$, where $\sigma(t)=\varepsilon(t)-\varepsilon(t_f)$, the integrated design model of pitch channel guidance control considering the attack angle constraint is:

$$\begin{bmatrix} \dot{\sigma} \\ \ddot{\sigma} \\ \dot{\alpha} \\ \dot{\omega}_z \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & -\dfrac{2\dot{R}}{R} & -\dfrac{C_y^\alpha QS}{mR} & 0 \\ 0 & 0 & -\dfrac{C_y^\alpha QS}{mv_m} & 1 \\ 0 & 0 & \dfrac{m_z^\alpha QSL}{J_z} & 0 \end{bmatrix} \begin{bmatrix} \varepsilon \\ \dot{\varepsilon} \\ \alpha \\ \omega_z \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ \dfrac{m_z^{\delta_z} QSL}{J_z} \end{bmatrix} \delta_z + \begin{bmatrix} 0 \\ d_\varepsilon \\ d_\alpha \\ \bar{d}_{w_z} \end{bmatrix} \tag{3}$$

The remaining variables in equation (3) are defined in References [6].

3. Research Status of Igc Method Considering Attack Angle Constraint Iterature

Since the concept of IGC was proposed, by establishing the connection between the guidance system and the control system, the coupling between the guidance system and the control system and the interaction between the movement of the missile center of mass and the movement around the center of mass can be fully considered. With the development of control discipline and the proposal of new control theory, scholars at home and abroad have applied advanced control methods to the integrated design of guidance control, and obtained better guidance performance, such as sliding mode control, adaptive control, optimal control, inversion control, dynamic surface control and automatic disturbance rejection control. The main design methods of guidance control integration considering angle of attack constraint and their advantages and disadvantages are summarized in Table 1.

3.1. Sliding mode control method

Sliding Mode Control (SMC), that is, sliding mode variable structure control, this control method has good robustness because it can design sliding modes and is independent of system parameters and external disturbances [7]. As a special control method, sliding mode control has been used by many scholars to study IGC design problems [8].

Shkolnikov et al. [9] used sliding mode control theory to design the guidance control integration algorithm, and they divided the guidance control system into two parts for design, inner ring and outer ring, but because this design method does not get rid of the shackles of traditional design, it does not belong to a complete guidance control integration design. In order to fully reflect the characteristics of the integration of guidance control, Shima et al. [10] studied the IGC problem based on sliding mode control by selecting the zero-controlled off-target amount as the sliding mode surface, but did not consider the non-matching characteristics of the model. Zha Xu et al. [11] fully consider the uncertainty and unmodeled dynamics of the system, and design a terminal sliding mode control strategy to cope with the non-matching uncertainty characteristics of the system, which ensures the stability of the system, and the simulation results show that the accuracy meets the design requirements. Qi Hui et al. [12] designed an integrated missile guidance control algorithm based on sliding mode control and inversion method, which can overcome unmodeled uncertainty and target maneuvering interference, and has strong robustness. Guo Chao et al. [13] considered the problem of interceptor missile guidance with attack angle constraint, and designed an integrated algorithm based on inverted sliding mode and extended observer, which can obtain a small amount of off-target and meet the terminal attack angle constraint. Liu Xiaodong et al. [14] designed an integrated design of three-dimensional guidance control considering the constraint of attack angle, and used continuous function instead of symbolic function to suppress the jitter problem of sliding mode control. Literature [15] considers the saturation problem of actuators, and designs a guidance law that satisfies the attack angle constraint based on the integration of guidance control.

Sliding mode control has the advantages of fast response and insensitivity to system uncertainty and external interference, so many guidance laws considering attack angle constraints are designed based on sliding mode control. However, there is "jitter" in sliding mode control, which has always been the main problem affecting engineering applications, so it should be paid attention to when using sliding mode control for the integrated design of guidance control.

3.2. Adaptive control method

Adaptive control can adaptively adjust control parameters and strategies according to changes when the system is perturbed or changing working conditions [16]. Adaptive control has the advantages of adapting to the uncertainty of the missile system and the complex flight environment.

Hou Mingzhe et al. [17] used the this control method to design an integrated control method, and the simulation results show that the method can not only ensure the strike accuracy of the missile, but also ensure the robustness of the missile system. Zhou Xiao et al. [18] carried out an integrated design of the missile pitch channel based on the adaptive inversion control method, which can effectively reduce the amount of missile off-target and shorten the response time of the missile system. Fu Hao et al. [19] aimed at the problem of separation of guidance and control loops in high-precision interception of high-speed and large-maneuvering targets, and studied the design of missile IGC based on L1 adaptive control, and gave the design of the controller. Gu Panfei et al. [20] considered the uncertainty parameters and interference of the control system terminal, and used adaptive fault-tolerant control to design the guidance and control integration of hypersonic aircraft, which proved the effectiveness and superiority of this design method. He et al. [30] designed an integrated guidance control law with attack angle constraint for maneuvering targets based on adaptive backfooting, and used smooth second-order sliding mode to estimate the differential of virtual control law.

The adaptive control method requires that the model structure of the system be known accurately in advance, and the uncertain parameters of the system meet the "linear parameterization" condition, so its application is limited. At present, the main research direction of adaptive control focuses on maintaining system stability and dynamic characteristics under the condition of disturbance and unmodeled error. In view of this problem, the main solution is to effectively integrate adaptive control with other control methods to improve the robustness of the control system.

3.3. Dynamic polygon control method

The Dynamic Surface Control (DSC) method was first proposed by Swaroop et al., which avoids the "differential explosion" problem caused by repeated derivation by introducing a low-pass filter in the inversion control design, and is widely used in the integrated design of guidance control.

Song Haitao et al. [21] comprehensively considered the modeling errors caused by approximate linearization and ignoring state coupling and input coupling, compensated the error of the interceptor missile, and then used the adaptive dynamic surface control method to design the IGC controller, which solved the controller design problem of this typical non-matching nonlinear control system. Hou et al. made a breakthrough considering the coupling factor between the three-dimensional control channels of the side-sliding turning aircraft, designed the three-dimensional guidance control integrated controller, and used the adaptive method to effectively estimate and compensate for the uncertain upper bound, which improved the robustness of the system. Qu Pingping et al. [22] considered the second-order dynamic characteristics of the missile autopilot and designed the guidance law based on dynamic surface control, but did not consider the problem of attack angle constraint. Liu Xiaodong et al. [23] developed a three-step guidance control integrated algorithm with strong robustness based on the dynamic surface block design and considering the attack angle constraint, but how to adaptively obtain the gain of the robust term was not studied. Lai Chao et al. [24] proposed an integrated design method of composite three-dimensional guidance control combining finite time convergence state observer and adaptive dynamic surface control to effectively improve the interception accuracy of large maneuvering targets in order to solve the problem of unknown target acceleration during the interception of large maneuvering targets. Zhao Bin et al. [25] proposed an integrated guidance control method to meet the all-JIT line of sight constraint based on the integral obstacle Lyapunov function and the dynamic surface method, which effectively solved the problem of field of view angle constraint. Wang Xinglong et al. [26] proposed an adaptive dynamic surface control method based on nonlinear observer, aiming at the problem that target acceleration information is difficult to be directly measured. Song Haitao et al. [27] used finite time observers to accurately estimate the uncertain terms in the integration, and solved the problem of non-matching uncertain terms by using the design steps of dynamic surface control. Han Xudong et al. [28] based on the dynamic surface sliding mode theory, the guidance control system was designed in an integrated manner, so that the projectile body hits the target at a specific angle and meets the field of view angle constraint of the seeker.

As an improved algorithm of inversion control method, dynamic surface control method can overcome the problem of "differential inflation", and is a favorable tool for the design of non-matching nonlinear system controllers.

3.4. Invert the control method

The Backstepping Control method, also known as the backstepping method, is a nonlinear system design method first proposed by Kokotovic [29] in 1991 and quickly thereafter Develop. The inversion control method is suitable for uncertain nonlinear systems that can be linearized in states or have strict parameter feedback [30].

Shu Yanjun et al. [31] designed a dynamic surface inversion control method based on nonlinear interference observer, which uses the dynamic surface method to eliminate the "computational inflation" problem in the traditional inversion design, which has higher guidance accuracy and better performance than the traditional independent design method of guidance control system. Ran et al. [32] used the inverted sliding mode control method to design the system in an integrated manner, but the algorithm was too cumbersome, which limited its engineering application to a certain extent. Liang et al. [33] designed an integrated guidance control algorithm based on the inversion control method, considering the influence of saturation factors and actuators. Ma Liqun et al. [34] introduced backstep control in integral control, and designed an integrated guidance control algorithm through the integral back-step method, which can realize the interception of tar-gets by missiles, enhance the anti-jamming ability of the system, and improve the robustness of the system.

The backstepping method has certain advantages in dealing with the uncertainty of nonlinear systems by dismantling complex nonlinear systems into multiple subsystems and assigning Lyapunov functions and intermediate virtual controls to each subsystem, thereby inferring back to the design of the overall control law. However, with the development of practical engineering application requirements, excessive differentiation of virtual control quantities often leads to an exponential increase in computational amounts, causing the problem of "differential inflation".

3.5. Feedback linearization method

Feed Back Linearization (FBL) transforms nonlinear system control problems into linear system control problems. Feedback linearization does not ignore any higher-order terms, so the resulting system is precise and holistic. On the other hand, since the system contains uncertain terms, its dependence on the accurate model needs to be resolved. Feedback linearization is a common method in the design of missile nonlinear flight control systems.

Menon et al. designed the guidance control integrated controller by feedback linearization under the premise that the model is known; Yin Yongxin et al. [35] in order to ensure the accuracy of guidance control and meet the attack angle constraints, the feedback linearization of the integrated model was carried out by differential geometry based on the influence of coupling factors in the system, but the influence of the characteristics of the actuator on the integrated design of guidance control was not considered. In order to improve the stability and accuracy of the missile when hitting large-maneuvering and high-speed targets, Ma Chen et al. used the feedback linearization method to design the integrated controller, and the results show that the method can effectively improve the system performance.

Feedback linearization is an accurate linearization method based on accurate models, which also has certain limitations in practical use. The disadvantage of this method is that it is very sensitive to the error of the system model, so further research has been carried out by scholars at home and abroad.

3.6. Self-disturbance rejection control method

Optimal control is widely used control theories in modern control history which can easily design the integrated model of guidance control and meet the requirements of guidance accuracy, dynamic characteristics, control quantity and other performance indicators. However, there are also difficulties in using the optimal control method, that is, the need to solve the Hamilton-Jacobi-Bellman (HJB) equation. Commonly used solution methods include state-dependent Riccati equations and θ-D methods.

Lin et al. were the first to use the optimal control theory to study the integration of missile guidance and control, and obtained the optimal control law, but the control law is for stationary targets. Pilumbo et al. [36] use the state-dependent Riccati equation method to solve the three-channel coupled guidance control integration design problem, but this method is computationally intensive. Hughes et al. [37] designed the integrated missile guidance control system based on the linear optimal control method for target interception problem, but the disadvantage is that this accurate linearization will lead to the complexity of the implementation of the method. Xin et al. [38] used the θ-D suboptimal control method to approximate the HJB equation to obtain an approximate closed-loop solution to the nonlinear guidance problem, the state-dependent Riccati equation (SDRE) Compared to the control method, it does not rely on the online calculation of the Riccati equation. Vaddi et al. [39] use nonlinear optimal control to design the guidance control integration system, and solve the HJB equation by SDRE method to improve the overall performance of the guidance control integration system, the disadvantage is that the online calculation amount is large. Yang et al. used the θ-D suboptimal control method to design an integrated method of guidance control considering the drop angle constraint. Finally, the feasibility and robustness of the proposed scheme are verified by simulation.

Optimal control is one of the most important theories in guided weapons. However, the effect of most of the existing optimal controls is highly dependent on the requirements of the mechanism model, and the uncertainty of the system is not considered, and the system robustness is poor.

3.7. Self-disturbance rejection control method

Active Disturbance Rejection Control (ADRC) was proposed by Han Jingqing on the basis of the PID control method in the 90s of the 20th century, and its core idea is to expand the state observer (Extend State Observer, ESO) [40] observes and estimates uncertainties of the controlled object and compensates for them in real time. ADRC is an ideal method to solve the control problem of complex uncertain systems. At present, the automatic disturbance rejection control has been successfully applied to many fields such as aircraft control, showing great potential and superiority.

Zhao Chunzhe et al. [41] aimed at the interception problem of maneuvering targets, based on the automatic disturbance rejection control, designed the missile integrated controller, and adopted a cascade ADRC design to avoid the difficulty of extracting the high-order derivative of the line of sight angle, which is not strictly consistent with the integrated design concept. Xue Wenchao et al. [42] proposed an integrated design method of three-dimensional guidance control based on the idea of disturbance rejection, which has the advantages of real-time estimation and compensation of the uncertainty in the flight control system, and has good robustness, but does not further analyze the performance of the closed-loop system. Dong Chaoyang et al. [43] proposed an integrated missile guidance control design algorithm based on self-disturbance rejection control and inversion terminal sliding mode control, which can quickly and accurately hit the target, and can obtain a small amount of off-target, and the simulation proves that the system has good robustness. Wang Wenwen et al. [44] adopted the AMB control technology and designed the AMB controller to estimate and compensate for the uncertain parameters and interference of the missile system in real time, which can achieve a good control effect. Zhao Kun et al. fully consider the coupling effect between channels and external random disturbance, and use the ADRC method to design an integrated control system with good dynamic characteristics and robustness, which can better meet the terminal angle constraint. Huang Luyu et al. [45] designed the guidance control integrated system by using backstep sliding mode and automatic disturbance rejection control, which improved the robustness of the system by using the compensator to correct the control command, so that the missile could accurately hit the target at the desired landing angle during the spiral maneuver.

The automatic disturbance rejection control can directly estimate and compensate for the uncertain dynamics inside the system in real time by using ESO, so it does not require accurate information of the model, nor does it need to assume that the uncertain model is linearized or bounded parameters, and the algorithm structure is simple, suitable for engineering applications. However, ADRC parameter selection is not easy, and the problem becomes complicated when the expansion state of the actual system is related to the system state, so once the engineering reality is considered, it is necessary to further explore and study how to better use ADRC.

Table 1: Three Scheme comparing.

method	merit	shortcoming
Sliding mode control	Fast response, insensitive to parameter changes and disturbances, strong robustness	It is easy to produce "jitter" problems
Adaptive control	Fast tracking speed and strong anti-interference ability	Rely on accurate system models
Dynamic polygon control	Avoid "differential inflation"	The upper limit of uncertainties needs to be estimated online
Inversion control	Dealing with non-matching uncertainties is straightforward	Inversion control
Feedback linearization	Precise linearization	Feedback linearization
Optimal control	Ability to optimize specified performance metrics	It is suitable for the object mathematical model to be accurately known, and the ability to cope with disturbances is poor
Disturbance rejection control	Uncertainties can be estimated and compensated in real time, without the need for precise information from the model	Parameters are not easy to select

4. Summary

From the perspective of integrated missile guidance control design considering attack angle constraints, this paper first constructs the three-dimensional projectile relative motion model, dynamic model and guidance control integrated model considering attack angle constraints in the pitch channel, and then systematically sorts out the typical literature and research status in this field at home and abroad according to the current guidance and control integrated design method.

Through the review of the existing literature, it is found that the integrated design of guidance and control is a relatively novel attempt, and the integrated design of guidance system and control system can greatly improve the overall performance of the system and has broad application prospects. However, as a complex nonlinear system, the strong coupling be-tween the systems and the fast time-varying nature of parameters bring great challenges to the integrated de-sign. The following shortcomings remain in current research:

1) Three-dimensional plane integrated design. Many of the existing guidance and control integrated design methods are completed in the two-dimensional plane, mainly around the model in the two-dimensional plane, ignoring the coupling relationship between the channels. However, in fact, there is a strong coupling relationship between the three channels of the missile, and the actual strike and interception occur in the three-dimensional plane. Only the study of guidance and control integration in a plane cannot fully consider the coupling relationship be-tween channels, which will lead to the overall performance of the guidance control integration system. Therefore, in the process of integrated missile guidance and control design, special attention should be paid to the design of guidance and control integrated system based on three-dimensional plane.

2) Full state coupling integrated design. Missiles are weapon systems with strong coupling characteristics of multiple inputs and multiple outputs. During actual flight, there is a strong coupling relationship between the three channels of pitch, yaw and roll. At present, some results have been achieved in the design of the IGC considering the angle constraint of missile attack, but most of the research is only aimed at the longitudinal plane or based on the idea of three-channel independent design to carry out guidance and control integration research. While it simplifies design difficulty, it affects the overall performance of the system. Therefore, it is very necessary to study the integrated design of guidance control with full state coupling of missiles.

3) Integrated design under multiple constraints. In the actual missile guidance and control system design process, in order to improve the damage effect of the warhead, avoid the occurrence of structural

damage to the projectile body, "stall" and other phenomena, and ensure that the instruments and components installed on the missile can work normally, the typical state of the missile, such as the end attack angle, angle of attack, side slip angle, etc., needs to meet certain constraints; In addition, problems such as saturation and failure faced by missile actuators will also have an important impact on the reliability and guidance accuracy of the guidance control system. However, so far, the study on the design of IGC under multi-constraint conditions has achieved few results, and further in-depth research is needed.

4) Integrated design with anti-interference and fault tolerance. Considering that the missile flight environment is harsh and complex, and different types of interference and random fault phenomena will affect the normal flight of the missile, it is necessary to carry out research on the IGC design method with anti-interference and fault tolerance. In the follow-up research, the integrated design method of guidance control under extreme flight conditions can be studied by combining adaptive control theory and robust control theory.

5) Integrated design that effectively handles un-certainties. There are many uncertainties in the integrated design of guidance control, including modeling errors, aerodynamic parameters, and target maneuvering, which will affect the control accuracy and stability of the system. Therefore, how to effectively deal with these uncertainties is also a practical problem that needs to be solved urgently. Although there has been a lot of research on this, with the continuous develop-ment of advanced theories and technologies in the field of control, the solution to this problem will be more optimized.

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