Design and Implementation of Trajectory Planning Algorithm for UAV Borne Air-to-Surface Missile

Kai Yang, Chen Xu and Yan Xu

Institute of modern control technology, Xi’an, 710065, China

Email: 415569717@qq.com

Abstract. This paper firstly introduces the development of domestic UAV borne air-to-ground missile guidance control systems and summarizes the current and ongoing research on the trajectory design of airborne missiles for unmanned aerial vehicles. Secondly, it introduces the traditional single-mode guided unmanned aerial vehicle air-to-ground missile trajectory design schemes and the new trajectory planning schemes for multi-mode compound guidance unmanned aerial vehicle borne air-to-ground missile. Finally, through mathematical simulation, it shows the characteristics of different trajectory schemes in terms of range, relative launch altitude and off-boresight capability.

1. Introduction
Looking at the recent local wars under the conditions of the modernization of the US military, drones are spending more and more money on the battlefield. The tasks undertaken have also expanded from Battlefield reconnaissance and surveillance to maritime patrol, anti-submarine warfare, ship-to-ship(ground) attacks, electronic interference, communication interception, target precise positioning, relay communications, and even extended to combat air missile defense, psychological warfare and network. Center warfare field. UAV has become an indispensable weapon platform for combat, and plays a pivotal role in the modern war under the conditions of informationization. It can be predicted that it will become a new force in the future information war, the "unmanned war." The development of UAVs in the United States is at the world's leading level. Its UAVs are technologically advanced and diverse. The first is the drones during the long voyage, including the "Global Hawk", "Predator", "Dark Star" and so on. The second is short-term and short-range drones, including RQ-7A "shadow" and "shadow" 600, "pointer" FQM-151A unmanned reconnaissance aircraft, "pioneer" drone, "Golden eye" 100, "longan" unmanned reconnaissance aircraft and so on. Third, micro-drones, mainly "Micro-Star" drones, "black widow" drones, "micro-ship" drones, "dollar" drones and so on. The fourth is unmanned combat aircraft, which mainly includes MQ-1 "Predator" unmanned reconnaissance/attack aircraft [1].

With its advantages of good maneuverability, high precision and small collateral damage, the open
space missile has received wide attention from various countries and has become an important part of unmanned airborne weapons. At present, foreign countries are developing unmanned air-to-air missiles using millimeter-wave/laser semi-active, millimeter-wave/infrared imaging, and multimode composite guidance systems such as millimeter-wave/laser semi-active/infrared imaging [2] And The country already has an unmanned airborne open space missile capable of attacking the ground, Its development history is: helicopter airborne open space missile prototype on board(limited attack package) → guidance component upgrade(attack envelope expansion) → single guidance mode new design(attack envelope lifting) → multi-mode composite guidance mode new design(all-direction attack). The development of unmanned airborne open space missiles in China is closely related to the development level of drones. In order to meet the needs of drone operations, unmanned airborne open space missiles have developed in the direction of long-range and autonomous development, adopting dual-mode or multi-mode guidance methods. In the face of a complex environment in a variety of targets can meet the requirements of combat. Therefore, this paper mainly studies the ballistic design law of unmanned airborne open space missile, and at the same time puts forward a new type of ballistic planning technology for unmanned airborne open space missile adapted to composite guidance and omnidirectional attack.

2. Ballistics Design of Unmanned Airborne Open Space Missile with Single Model Guidance

At present, the most widely used laser single-mode guided unmanned airborne open space missile series in China uses a helicopter airborne open space missile prototype(limited attack envelope) → guidance component upgrade(attack envelope expansion) → new design of a single guidance model(attack envelope greatly increased) development ideas, The series of missiles are upgraded and improved on the basis of helicopter platform open space missiles, and can be attached to Air Force drones. At the same time, they are equipped with combat platforms such as Naval helicopters, shipborne drones, and army helicopters [3] This series of missiles adopts a ballistic planning scheme with a high altitude along the sighting line. Generally, two ballistic laws are used. The specific ballistic design scheme is shown in figures 1 and 2.
3. Results of ballistic simulation of unmanned airborne open space missile with single-mode guidance

Figure 3 ~ figure 6 is the ballistic simulation results of the enhancement of the capability of a type of laser single-mode guided unmanned airborne open space missile. The ballistic law is the height of the flight after climbing to a predetermined height with the relative initial sighting line, and is transferred to the ballistic form of proportional guided dive. The missile's largest launch site is up to 9,000 meters high, with a range of up to 15Km, and an off-axis launch capability of up to 25 degrees, which is a significant increase in the launch envelope of missiles that are airborne by the first type of drone in China.

Figure 2. Ballistic law of UAV-borne air-to-ground missile guided by single mode 2.

Figure 3. Range-altitude curves of different field heights under 0 degree off-axis conditions.

Figure 4. High Speed Curves of Different Fields under Off-axis Conditions at 0 Degree.
4. **Ballistics design of multi-mode composite guidance unmanned airborne open space missile**

The increase in range is one of the directions for the development of unmanned airborne open space missiles. The range of the Haier series missiles developed in the 1970s was 9 km, and the range of the missiles in the three-mode JAGM project launched in 2008 reached 28 km. The range of smaller, unmanned airborne open space missiles is also increasing. For example, the short sword missile proposed by MBDA in 2012 has a range of about 30 km, which is also much larger than previous models such as spikes and LMM. With the increase of the range of the unmanned airborne open space missile, the commonly used semi-active laser guidance range is limited, and it is difficult to meet the demand of missiles in actual operations in the future. This has prompted the guidance system to lead from single-mode guidance to multi-mode guidance, so that the multi-mode composite guidance method has become an inevitable choice. Its advantage is that the multi-mode composite guidance system can give full play to the advantages of each frequency segment or each guidance system and make up for each other's deficiencies. The anti-jamming ability and combat effectiveness of weapon systems are greatly improved. At present, open space missiles using millimeter-wave/laser semi-active, millimeter-wave/infrared imaging, and multimode composite guidance systems such as millimeter-wave/laser semi-active/infrared imaging are being developed abroad. The most typical multi-mode composite guided open space missile is the "dual-mode sulfur stone"(DMB) missile developed by the United Kingdom. It uses a millimeter-wave/laser semi-active dual-mode guidance system and a joint open space missile(JAGM) developed by the United States. Using millimeter-wave / laser semi-active/infrared imaging three-mode guidance system [4].

Therefore, a new design of multi-mode composite guidance mode(all-direction attack) of unmanned airborne open space missile is proposed in our country to meet the needs of drone operations. The unmanned airborne open space missile is developing in the direction of long range and autonomy.
4.1 Intelligent planning and design of pitch attitude scheme for the initial guidance section of a multi-mode composite guided unmanned airborne open space missile

When an open space missile is launched under large airspace conditions, the initial pitch attitude scheme signal needs to change from the initial shooting angle to the desired transition angle, under different launch Heights, different implicated speeds, and different range target conditions. The desired attitude scheme signal variation law is quite different, the traditional attitude scheme number table can not meet the requirements [5]. In order to solve the above problems, a simple, unique, effective and easy to engineering application of pitch attitude scheme signal intelligent planning design method is proposed. According to the initial conditions such as the relative relationship between the target of the launch time, the flight speed of the aircraft, and the firing angle, the starting point, end point, change rule, and switching timing of the pitch attitude signal are designed to complete the intelligent planning of the signal. The initial value of the transmitted element information and attitude scheme signals are used to generate pitch attitude scheme signals, which can adapt to the conditions of aircraft flying in large airspace and launching in large attack envelope areas, the attitude scheme control process and the control loop switching process. Smooth change of missile pitch angle. The intelligent planning diagram of the pitch attitude scheme is shown in figure 7, and the intelligent planning design results of the pitch attitude scheme under typical launch conditions are shown in figure 8.

![Figure 7. Intelligent Planning of Pitch Attitude Scheme Signal.](image)

![Figure 8. Design of Intelligent Planning Signal for Pitch Attitude Scheme.](image)

4.2 Design of optimal trajectory planning for guidance section in missile trajectory with multi-mode composite guidance and unmanned airborne open space

Under the conditions of high-altitude launch, a mid-guidance optimal ballistic planning and design scheme for attacking targets with large field ranges of unmanned airborne air-to-surface missiles is proposed. This plan first solves the missile height control and control position online, and then sets up a virtual target position. Then through the analytical algorithm to plan the optimal guidance trajectory scheme [6]. This scheme is suitable for the guidance section flight of the composite guided unmanned
airborne air-to-surface missile, which is not only beneficial to the mid-terminal guidance transfer, but also improves the probability of the target intercepted by the mm wave head search, and at the same time maximizes the attack boundary of this type of missile. The timing design of HQC: In the attitude control section, the optimal moment of HQC is solved in real time with the minimum missile attitude and ballistic fluctuation as the constraint condition.

Virtual target setting: According to different terminal guidance methods, the virtual target position can be set. For example, according to the millimeter wave guide head, the ground angle can be small, the action distance is near, and the instantaneous field of view is small [7]. The virtual target position is set up to achieve a flat trajectory mode along the horizontal plane within a certain distance of the target, creating favorable conditions for the millimeter-wave seeker to search and intercept the target.

Multi-mode composite guided unmanned airborne open space missiles. The design results of the mid-guidance ballistic planning curve and the optimal attitude transition curve under typical launch conditions are shown in figure 9 ~ figure 10.

4.3 Design of all-direction attack scheme for unmanned airborne open space missile with multi-mode composite guidance

The full-scale attack is divided into three sections: turning control section, gliding tracking control section and proportional guidance section. Among them, the OB in the turn control section is mainly used for fast turning of missiles, and the body posture and orientation are adjusted for the follow-up tracking of attack targets; The gliding tracking control section BC is mainly used to track the target and control the missile into the seeker capture domain, providing a good state for the terminal guidance section; Proportional guidance section CT, using proportional guidance control, accurately hits the target [8] And ... The design diagram of the omnidirectional attack scheme is shown in figure 11, and the design results of the omnidirectional attack scheme under typical launch conditions are
shown in figures 12 to 14.

Figure 11. schematic design of omnidirectional attack scheme.

Figure 12. Design results of omnidirectional attack scheme.

Figure 13. Range-deviation curve of omnidirectional attack scheme.

Figure 14. Range-Height Curve of Omnidirectional Attack Scheme.

5. Results of ballistic simulation of unmanned airborne open space missile with multi-mode composite guidance

Figure 15 ~ Figure 22 is the results of ballistic simulation after the new design(all-direction attack) of a type of multi-mode composite guided unmanned airborne open space missile. The ballistic law is the optimal ballistic planning scheme for medium-guidance, and the mid-guidance final stage is
transferred to the flat trajectory mode. After entering the proportional guidance, dive to attack the target. The missile's largest launch site is up to 12,000 meters high, with a range of up to 20Km, and an off-axis launch capability of up to 180 degrees, which is significantly higher than the launch envelope of the unmanned airborne open space missile currently being studied and equipped in China.

Figure 15. 12000 m field high trajectory design results.

Figure 16. 9000 m field high trajectory design results.

Figure 17. 6000 m field high trajectory design results.

Figure 18. 3000 m field high trajectory design results.
6. Conclusion
With the advent of unmanned combat aircraft, drones will change their status in the past, when they mainly performed combat support tasks such as aerial reconnaissance, Battlefield surveillance, and
combat damage assessment, and will be upgraded to be able to execute anti-enemy air defense systems and ground attacks. One of the main combat equipment that can even perform air combat missions. In the new version of the "Road Map for UAV Development" of the US military, a total of nine clear goals for unmanned aerial vehicle systems were proposed, the first of which is to further develop the "Joint Unmanned Air Combat System." The task of suppressing enemy air defence(SEAD) forces, armed attacks and electronic attacks in a high-threat environment is carried out and listed as the most important goal in the road map. The U.S. military will step up its research and development efforts in unmanned attack aircraft, unmanned fighter jets, unmanned aerial early warning aircraft, and multi-functional drones. It is foreseeable that drones will become the main force for future air warfare. This article combs the guidance control system of the unmanned airborne open space missile in China. It has experienced the prototype of helicopter open space missile(limited attack packet) → guidance component upgrade(attack envelope expansion) → new design of single guidance mode(attack envelope lifting) → new design of multi-mode composite guidance mode(all-direction) The development history of the attack summarized the ballistic design of the unmanned airborne open space missile in active service and in research, introduced the ballistic design of the traditional single-mode guided unmanned airborne open space missile and the new ballistic planning of the multi-mode composite guided unmanned open space missile. The numerical simulation of different ballistic schemes in range range, launch site height and off-axis capability is also carried out.

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