Integration of guidance and fuze of directional warhead missile

Zhengjie Wang, Wei Li, Ningjun Fan

Abstract**—**Guidance and fuze separated system could not always achieve the attitude requirements of directional warhead at end-game attack stage. It is necessary to include guidance system in fuze-warhead coordination system. The hit probability and the effectiveness of warhead could be improved by utilizing the integration of guidance and fuze technology. Adopting target-hit function as the basis of adjusting control strategy, trajectory and attitude control requirements in the end stage could be met. An example which shows the advantages of integration of guidance and fuze is given.

Keywords**—**Integration of guidance and fuze; Fuze-warhead coordination; Target hit function

I. Introduction

FIXED-AIM warhead technology seeks to reduce the weapon system weight and to increase the accurate strike capability by using a highly directional warhead. That means the destroying fragments are projected in a direction normal to the missile longitude axis. In order to be effective, this kind of warhead should keep a specific attitude with respect to the target. Conventional approach of missile and target engagement modeling is used under the ballistic trajectory restrictions. However, for the fixed aim warhead, not only the trajectory restrictions should be considered, but also the attitude ones are supposed to be satisfied.

The effectiveness of warhead is decided by the two kinds of capabilities of missiles: the one is how to deliver the warhead to the trajectory which contains the optimal explosive point; the other is the capability that the fuze system detonates the warhead at the optimal explosive point. Since the structure of fuze system and the one of guidance system are separated which functioned distinct stages and it is impossible for fuze system to choose the attack trajectory, the traditional research method always places the emphasis on the latter. In the stage of attacking, for a weapon system, the guidance miss could not be decreased, what it can deal with is to choose the best explosive time based on existed guidance miss. In this way, the traditional detonation control is a relative optimal method. However, the goal of detonation control is always made great effort to minimize the guidance miss and maximize the effectiveness of warhead. Driven by this force, the technology of integrated guidance-fuze (IGF) comes up. This paper presents the nature of the fuze-warhead coordination, and the meaning of IGF is also discussed. Moreover, the paper emphasizes the control technology of the integration. Some comparisons of the destroy effectiveness of warhead with the IGF and the one without are given in this paper.

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Zhengjie Wang is with the School of Aerospace Science and Engineering, Beijing Institute of Technology. (phone: +86 – 10 - 68914465, fax:+86-10-68948292, email: wangzhengjie@bit.edu.cn)
Wei Li, Ningjun Fan are with the School of Aerospace Science and Engineering, Beijing Institute of Technology. (aegeanwei@gmail.com, njfan@bit.edu.cn)

II. Nature of fuze-warhead coordination

Fuze-warhead coordination is related with adjusting and harmonizing among target, fuze and warhead at the attack stage. The two dimensions' control, "time and space", is resolved through fuze-warhead coordination to detonate the warhead at the best position and time. The nature of fuze-warhead coordination is to achieve the maximum destruction to the target by utilizing the position and characteristic information of target. Theoretically, fuze system could absorb any information which helps the missile to distinguish a target from its environment. Combined with target and warhead, it should form a close-loop system, which could provide the feedback of destroy effectiveness to the weapon system. According to that, the fuze system could adjust and correct detonation position. However, for the weapon whose fuze system and guidance system are separated, once the fuze system sends out the detonating signal to the warhead, the procedure of detonation control is over for single attack. Actually, what the fuze, warhead and target are formed is an open-loop control system, and it is impossible to correct the detonation control miss for fuze system. Therefore, any random miss would generate great attenuation of the warhead.

III. Necessity of guidance and fuze integration

From the perspective of information acquirement, the fuze-warhead coordination system comprises not only target, fuze and warhead, but also the guidance system. The essence of the guidance system should be to measure and estimate position and movement of target. There is one difference between guidance system and fuze system: the former has to function at track trajectory; the latter has to operate at the attack trajectory. Supposed that the blast position of warhead is decided by the fuze combined with the guidance, for single attack, the destroy effectiveness could be greatly improved.

From the perspective of control, the guidance system should be included in the fuze-warhead coordination system.

Guidance system manipulates the missile according to certain law in order to adjust the direction and velocity of the movement. Likewise, there is a difference between fuze and guidance: the former exerts effect on the missile to dwindle the guidance miss; the latter dominates the blast time of warhead to maximize the effectiveness of warhead on the attack stage. They have the same purpose: the little the guidance miss is, the sounder the control of fuze system will be. Additionally, if the fuze-warhead coordination system contains the guidance which is a sort of close-loop, the detonation control would appear to a close-loop in real meaning.

From the stand of system, the guidance should not be excluded from the fuze-warhead coordination system. They are correlated, mutual restricted. More importantly, it is necessary to take guidance, fuze and warhead together into account to maximize the effectiveness of warhead.

IV. Engagement Modeling

Before describing the integration of guidance and fuze technology, some frames of reference and model of engagement are needed to describe. A six-degree-freedom nonlinear dynamic model of an air-to-ground warhead missile is employed in the present research. The missile equations of motion are expressed in the body coordinate system x, y, z illustrated in figure. And the most commonly used reference frame is the earth-fixed reference frame x_g, y_g, z_g. Successful attack of the warhead requires the missile approach the target as close and as parallel as possible, while maintaining a specific roll orientation to direct the warhead fragments towards the target.

The methods of evaluating the effectiveness of target-hit should be distinct based on different types of missile system. In the present research, a relative simple approach is given—target-hit function. Since the precondition of destroying target is whether the blast fragment hits the target, the principle of evaluation could be assumed as target-hit. The definition of the target-hit function is the sum of the square of hit miss in the x and z direction. It could be computed as follows:

$$S = (\Delta X)^2 + (\Delta Z)^2 < R^2$$

$$\Delta X = (x_m - x_t) - (V_{mx} - V_{tx}) \cdot t + (y_m - y_t - V_{my} \cdot t) \cdot \tan\theta$$

$$\Delta Z = (y_m - y_t - V_{my} \cdot t) \cdot (\tan\lambda - \tan\gamma)$$

$$\lambda = \arctan \frac{z_m - z_t - (V_{mz} - V_{tz}) \cdot t}{y_m - y_t - V_{my} \cdot t}$$

Where: x_m, y_m, z_m -- the position of the missile

x_t, y_t, z_t -- the position of the target

V_{mx}, V_{my}, V_{mz} -- the velocity of the missile in x, y, z direction

V_{tx}, V_{ty}, V_{tz} -- the velocity of the target in x, y, z direction

θ -- the pitch angle

γ -- the roll angle

λ -- the line of sight in the yoz plane

R -- the radius of vulnerable area of target

The formula shows the deflection between the position (actual hit point) when the blast fragments' velocity decreased to zero and the aim point (potential hit point). ΔX means the deflection between actual hit point and aim point in the x-axis direction. ΔZ means the deflection in y-axis direction. If the vulnerable area of target is simplified as a circle with radius R, it makes sense that when S is greater than R^2, blast fragments would not destroy the target effectively. To achieve optimal effectiveness of warhead, it is desirable to make value of S as little as possible to increase the probability of kill. It could be achieved through two kinds of approaches. On one hand, the deflection in x direction could be diminished by fuze system; on the other hand, the deflection in z direction has to be controlled by the guidance system. From the expression of S, the scenarios of x and z direction could be discussed separately while the pitch angle is little. Generally speaking, it is possible to achieve $\Delta X = 0$ through adjusting the fuze time-delay. Therefore, what we want is to adjust the guidance system to minimize the ΔZ.

From the derivative of S, we could get if $\gamma = \lambda$, the correspond result of S would come up the minimum value. However, in the traditional detonation control approach, it is impossible to realize the above requirement. It is necessary to rely on the guidance control system to fulfill the requirement. Therefore, by applying integration of guidance and fuze technique, the incapability problem of the fuze system could be settled.

V. Integration of Guidance and Fuze

The definition of integrated guidance-fuze (IGF) should be given: the fuze and the guidance are combined together on conception, design of structure and circuit, signal processing and so on to absorb the measurement information adequately and to improve the effectiveness of warhead greatly. For information acquirement, guidance and fuze system utilizes only one set of hardware platform, including target detector, sensors, and missile-borne computer. For signal processing and control, information of target and missile communicates continuously between fuze and guidance until accomplishing the trajectory control, the selection of aim point, and detonation control.

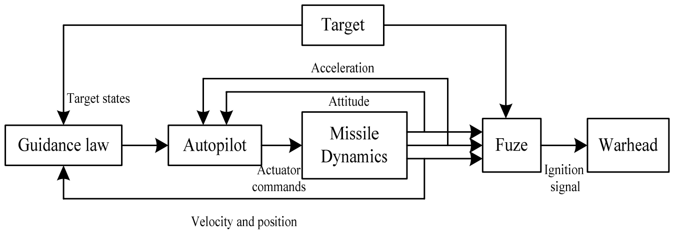

Fig. 1 Guidance and fuze separated

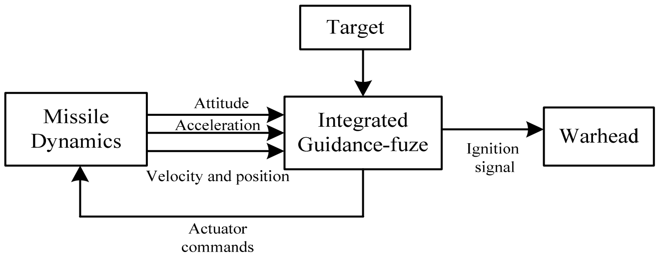

Fig. 2 Guidance and fuze integrated

Figure 1 and figure 2 illustrate the differences between traditional and integrated guidance-fuze system. In the conventional approach, the guidance system and the fuze system are separated. The fuze-warhead coordination system does not include guidance system. As a result, in engagement of target and missile, the fuze system cannot adjust the attack trajectory or the missile's attitude. If the guidance miss exceeds the requirements or the missile does not achieve a specific attitude orientation with respect to the target at interception, the warhead could not destroy the target effectively.

On the other hand, in the integrated approach, the guidance system and the fuze system could use all the available measurements. As a result, the system is desirable to become a close-loop system. Moreover, the weapon system weight could be reduced and the effectiveness of warhead could gain enhancements.

While there are definite operational advantages in using integrated guidance-fuze systems, their design is complicated. This is due to the fact that the IGF increases the dimensions of the nonlinear control which make it difficult to apply the conventional gain-scheduling design methodology. These high-order designs may require gain scheduling not only with respect to the airframe performance variables, but also with respect to the engagement geometry. Computer-aided nonlinear control system design methods offers approaches for integration design.

Another difficulty in IGF system design arises from the fact that the control strategy has to be made out according to the predicted miss. Most control techniques available on missile are not related with the evaluation of damage effectiveness. As a result, it is incapable to provide the feedback of the damage to the guidance system to adjust control strategy. The following section will mainly discuss how to make out control strategy based on the evaluation of damage effectiveness. The IGF system has the task of providing the detonation signal and evaluating the effectiveness of target-hit. As a result, evaluation of target-hit effectiveness is vital in IGF for two reasons: on one hand, it is the determinate factor to ignite the warhead; on the other hand, it is the dependence of adjusting the attack trajectory and attitude of missile. According to the mentioned above, usually speaking, when λ is not a constant, the fin deflection should always being adjusted to fit for the requirement. Therefore, inevitably, the accuracy of trajectory would be undermined. It is desirable to make λ equal to zero on the guidance control stage to avoid big trajectory deflections. In this strategy, the deflection between target and missile in the z direction and the roll angle of the missile should maintain to zero. On the other hand, if the line of sight in yoz plane is not equal to zero at the end-game stage, the control system has to adjust the roll angel equal to λ.

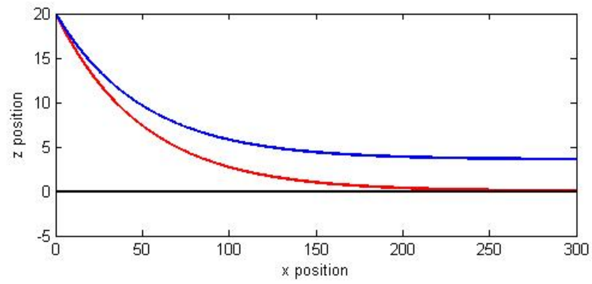

Fig 3 Position time histories in x and z direction

The missile and target positions with respect to the inertial frame are shown in Figure 3. It may be observed in this figure that the missile continuously turns towards the target to reduce the deflection in z direction. The red curve shows that at the end-game stage the deflection almost decreases down to zero, and the bull curve shows the scenario of that beyond zero. Therefore, accordingly, roll angle should be adjusted like the figure 4.

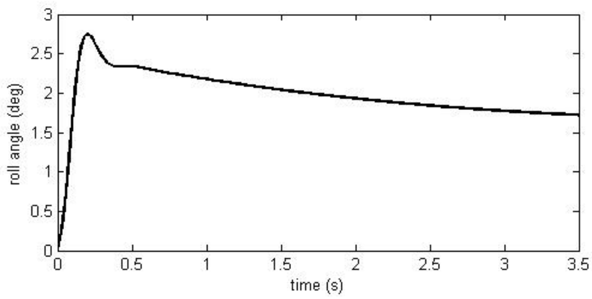

Fig 4 Roll angle history

Figure 4 shows the history of roll angle when the line of sight could not be decreased to zero. With the time lapsing, the roll angle tends to keep with the line of sight.

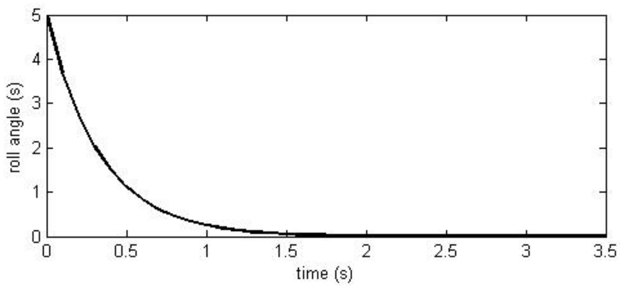

Fig 5 Roll angle history

Figure 5 shows the history of roll angle when the deflection in z direction equals to zero at the end-game stage. In the ideal situation, the roll angle could be quickly settled down to zero in order to satisfy the attitude requirements in engagement. The IGF system maintained the roll angle near zero till the very end.

VI. Simulation Results

The advantages of IGF in the accurate strike could be illustrated by a simulation example. The object of simulation is certain type of loitering missile. The speed of attack is 100 m/s. The initial line of sight is assumed as 5 degree.

Tab1 Comparison of target hit function value

Explode time / Target hit Function value	0.98	0.99	1.00	1.01	1.02	1.03	1.04	1.05	1.06
Without IGF	17.3	10.7	6.14	3.60	3.09	4.62	8.18	13.7	21.4
With IGF	14.1	7.60	3.06	0.85	0.07	1.62	5.22	10.8	18.5

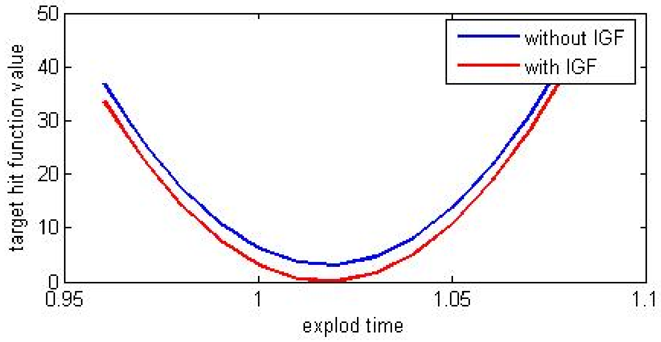

Fig 6 Target hit function value

From the figure 6, where the blue curve presents the scenario without IGF and the red presents that with IGF, with the same assumptions, the target hit function value with IGF is little than the one without IGF, which means that the probability of kill is higher. At around optimum explode time, the target hit function value with IGF is close to zero, indicating that the deflection of target-hit is very tiny.

VII. Conclusions

The integration of guidance and fuze comprises the evaluation of probability of kill and the trajectory and attitude control. For directional warhead, the warhead should satisfy the requirement of trajectory and the restriction of attitude. Therefore, applying the IGF, the control strategy is adjusted based on the evaluation of probability of kill. This paper presented the target hit function as the control basis. For a sample engagement scenario analyzed in this paper, the IGF system produced the small miss distance compared with traditional fuze system. Future research will concentrate on the control algorithm at the end-game stage.

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Zhengjie Wang was born in Jilin, China, in 1973. She received B.E and Ph.D. degrees in aircraft design and control engineering from the Beijing Institute of Technology, Beijing, China, in 1996 and 2001 respectively. In 2005, she got the bilingual teaching training in the University of the West of England, UK.

After graduation, she became a lecturer in the Department of Aerospace Engineering at the Beijing Institute of Technology and became an Associate Professor from 2003 till now. From 2008 to 2009, she served as a visiting scholar at Cranfield University, UK.

Her research interests are in the areas of systems modeling and simulation, control theory and applications, especially advanced control algorithm and its applications to aircraft control systems, and micro system design.