Relaxed Stable Stability Technology for an Air-to-air Missile

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Abstract: *Relaxed Stable Stability (RSS) in an important part of the active control technology. It is a new way to raise the flying speed, distance and maneuverability of missile. Depth study of RSS technology plays an important role for the new concept missile design. This paper describes the detailed definition of RSS and its advantages, presents the research status and prospects for its application in the design of new missiles.*

Key words: missile; active control technology; relaxed stable stability; new future missiles

1 Introduction

Relaxed static stability is one of the main branches of active control technology. Active control technology was first born in the field of aircraft design; it considers the impact of a control system on overall design in the early design process. So it can play the potential of a control system. In recent years, it has gradually been used in the design of an air-to-air missile.

RSS technology was originally used in the aircraft field. In 1960s, requirements on aircraft maneuverability was higher and higher. With rapid development of modern automatic flight control technology and computers, RRS and other active control technology has been proposed and developed. In the 1970s, electronic equipment and computer performance made great strides; optimal control theory, the servo loop design and system functional analysis development laid the foundation for RSS technology. Subsequently, the United Kingdom, France, Germany, and Japan application have adopted the advanced technology and its in new aircraft and missiles. Increasingly the number of air-to-air missiles in the world using the RSS technology, large angle of attack and mobility promoted the development of it [1-4].

Missile stability refers to a missile in the case of an outside disturbance; when the disturbance effects are eliminated, it can automatically restore to its original state of equilibrium. The center of missile whole mass was called center of gravity, and the center of all aerodynamic force on the missile was called pressure center. Were denoted by X_t and X_d, respectively, and static stability is $\Delta X = X_t - X_d$. The pressure center is always behind the center of gravity when a missile is in a stable state. If missiles are subjected to an outside disturbance, attitude angles change, but the missile can return to its former state when disturbances dismiss. (see Figure 1)

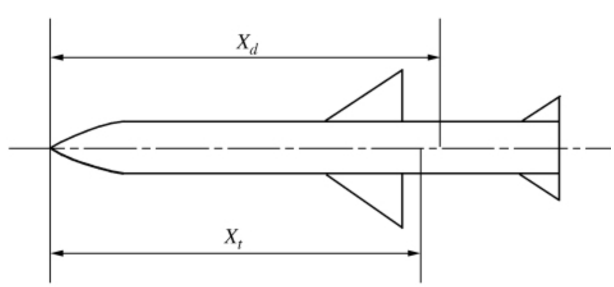

Figure 1 Static stable missile

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If we use a RSS design missile, the pressure center is always in front of the center of gravity. On the contrary, where missiles are subjected to outside disturbance, attitude angles change and the missile can not return to its former state when disturbances dismiss. (see Figure 2)

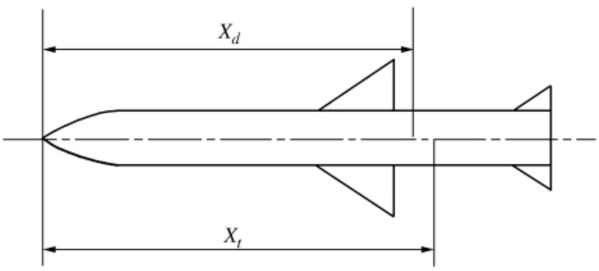

Figure 2 Relaxed static stability missile

2 Performance advantages of the RSS missile

RSS theory has been an extensive research. There are mainly two ways to make a missilne static unstable. Change the structure of the wings and installation location to move the focus position, and change the arrangement of internal devices to adjust the center of gravity position. When a missile is static stable, forces on wings and body will take a pitch moment, and the moment can make a missile anticlockwise deflection. This will be balanced by force of rudder. Lift is generated by the rndder in the opposite direction with the missile body, so this will reduce the total lift. When a missile is in an unstable state, lift is generated by the rudder in the same direction with the missile body; this will increase total lift, increasing the maneuverability [5]. (see Figure 3)

Missile stability and maneuverability is related with static stability. The more missile static stability, the better motion stability, but less missile maneuverability. On the contrary, the less missile static stability or unstable, the worse motion stability, but the better missile maneuverability. In a given flight speed and altitude, overload of a missile depends on the angle of attack, sideslip angle and rudder deflection angle. If the missile aerodynamic shape is unchanged during the flight, the available overload will increase [6~9].

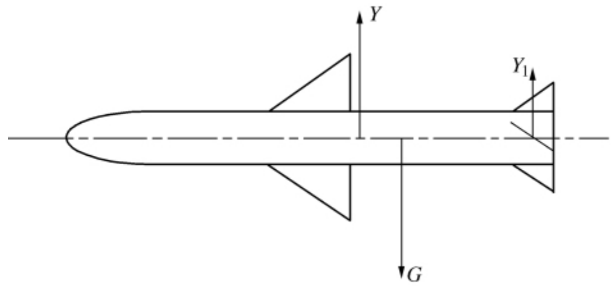

Figure 3 Force on RSS missile

To achieve the missile given straight rise, available engine thrust should be greater than the required thrust in level flight. A RSS missile in level flight required thrust is less than the design of a static stable missile. So the residual thrust and lift angle are big. RSS design can increase the maximum level flight speed of a missile, and reduces the least level flight speed, so this will help to select a wide range of flight speed.

When the RSS missile center of gravity is backward, the force of trimming a missile body and wings on the rudder decreases and rudder area and mass can be reduced. These have a positive meaning on enhencing missile flight performance. In short, RSS technology is a new way to enhence missile performance [10].

3 Static stability and dynamic stability

To study RSS technology, it is necessary to find out missile stability, as well as the relationship between static stability and dynamic stability. Longitudinal disturbance movement of the missile can be broken down for long-period perturbation motion and short-period perturbation motion. Short-period perturbation motion has high oscillation frequency and fast amplitude decay. Long-period perturbation motion is the opposite. The value of the motion parameters is obtained by superimposing two components [1]. Changes of long-period perturbation motion is very long, so in the beginning of a disturbance movement short-period perturbation motion plays a dominant role. The vertical movement of the missile is usually decomposed into two independent stages. Short-period perturbation motion analysis can solve many practical problems in the design of the missile and control system.

Missile longitudinal perturbation equations of motion are high order differential equations. The long-period motion is negligible. Here $\Delta V = 0, \Delta \dot{V} = 0$, so the equation of motion can be written as:

$$\begin{cases} \Delta\ddot{\vartheta} + a_{22}\Delta\dot{\vartheta} + a'_{24}\Delta\dot{\alpha} + a_{24}\Delta\alpha = -a'_{25}\Delta\dot{\delta}_z - a_{25}\Delta\delta_z + M_{zd} \\ \Delta\dot{\theta} + a_{33}\Delta\theta - a_{34}\Delta\alpha = a_{35}\Delta\delta_z + F_{yd} \\ \Delta\vartheta - \Delta\theta - \Delta\alpha = 0 \end{cases} \tag{1}$$

Equation of state is as follows:

$$\begin{bmatrix} \Delta\dot{\omega}_Z \\ \Delta\dot{\alpha} \\ \Delta\dot{\vartheta} \end{bmatrix} = A\begin{bmatrix} \Delta\omega_Z \\ \Delta\alpha \\ \Delta\vartheta \end{bmatrix} + \begin{bmatrix} -a_{25} + a'_{24} \\ -a_{35} \\ 0 \end{bmatrix}\Delta\delta_z - \begin{bmatrix} a'_{25} \\ 0 \\ 0 \end{bmatrix} \cdot \Delta\dot{\delta}_z + \begin{bmatrix} a'_{24}F_{yd} \\ -F_{yd} \\ 0 \end{bmatrix} \tag{2}$$

Where:

$$A = \begin{bmatrix} A_1 & A_2 & A_3 \\ 1 & A_4 & a_{33} \\ 1 & 0 & 0 \end{bmatrix} \tag{3}$$

$$\begin{cases} A_1 = -(a_{22} + a'_{24}) \\ A_2 = (a'_{24}a_{34} + a'_{24}a_{33} - a_{24} \\ A_3 = -a'_{24}a_{33} \\ A_4 = -(a_{34} + a_{33}) \end{cases} \tag{4}$$

The short-period perturbation motion characteristic equation can be obtained by matrix A.

$$D(s) = s^3 + A'_1s^2 + A'_2s + A'_3 = 0 \tag{5}$$

Where:

$$\begin{cases} A'_1 = a_{22} + a_{34} + a'_{24} + a_{33} \\ A'_2 = a_{24} + a_{22}(a_{34} + a_{33}) + a'_{24}a_{33} \\ A'_3 = a_{24}a_{33} \end{cases} \tag{6}$$

Missile dynamic coefficients are known, so we do not choose a more cumbersome means to calculate the characteristic roots to determine the stability or not, but according to the Hurwitz criterion if the missile has a static instability, $a_{24} < 0$. When the missile steady straight line climb, $a_{33} < 0$, $a_{24}a_{33} > 0$, the movement will likely be stable. When a missile is plummeting, the opposite movement will be unstable. If the missile is in straight and level flight, $a_{24}a_{33} = 0$, the characteristic equation will have a zero root. The gravity force coefficient increases with the flight speed and its value is very small. Practice has proved that if $a_{24}a_{33} \neq 0$, the characteristic equation has a small root. And if $a_{24}a_{33} = 0$, the root can be replaced by zero, another two roots have little change. So we get:

$$s^2 + (a_{22} + a_{34} + a'_{24})s + (a_{24} + a_{22}a_{34}) = 0 \tag{7}$$

Where $a_{22} > 0$, $a_{34} > 0$, $a'_{24} > 0$, and there must be $a_{24} + a_{22}a_{34} > 0$, and

$$-m_z^{\omega_z}\frac{L}{V} \cdot \frac{P + Y^\alpha}{mV} > m_z^\alpha \tag{8}$$

The above equation shows that the missile can be unstable. However, in order to maintain the dynamic stability of the missile, static instability can not be too large. Dynamic stability and static stability are intrinsically compled, but both have a strict distinction.

Research on the perturbation problem caused by rudder deflection is to control and stabilize the flight of missiles. Changes of pitch angle, pitch rate and angle of attack are caused by rudder deflection. And rudders can make the missile flight in accordance with the control requirements. In the short-period perturbation motion, rudder angle for the pitch rate transfer function of a static unstable missile is as follows:

$$W_{\delta\vartheta}(s) = \frac{K_\alpha(T_{1\alpha}s + 1)}{s(T_\alpha^2 s^2 + 2\xi_\alpha T_\alpha s - 1)} \tag{9}$$

Where:

$$\begin{cases} K_\alpha = \dfrac{a_{25}a_{34} - a_{24}a_{35}}{a_{24} + a_{22}a_{34}} \\ T_\alpha = \dfrac{1}{\sqrt{a_{24} + a_{22}a_{34}}} \\ \xi_\alpha = \dfrac{a_{22} + a_{22}a_{24}}{2\sqrt{a_{24} + a_{22}a_{34}}} \\ T_{1\alpha} = \dfrac{a_{25} + a'_{24}a_{35}}{a_{25}a_{34} - a_{24}a_{35}} \end{cases} \tag{10}$$

If the missile is given static instability in the design phase, it will have a distinct advantage over the static stable structure. With the reduction of missile static stability, the value of a_{24} decreases, so the Equation (9) denominator decreases and the numerators increase. These all can increase missile maneuverability. However, the static instability is not the only influence factor. Flying speed and height can also have an effect on maneuverability. The air density is decreased as the altitude increases, so maneuverability of the missiles decrease. But transient time is longer as static instability increases and time increases will affect the maneuverability. Missile static instability can not be made too large. General requirements for the design of the missile control system frequency are higher than the natural frequency of the missile body. Static unstable missile natural frequency is lower than a static stable missile, so it provides better conditions for autopilot design [12~16].

4 Summary

In half a century, air-to-air missile is about to enter the fifth generation to the adapt to the new air threat target hit is the core requirements of the fifth-generation air-to-air missile. Future air-to-air missiles can deal with a variety of targets including a fourth-generation fighter, unmanned combat aircraft and supersonic cruise missiles. Modern warfare improves missile performance requirements. The traditional missile design methods are restricting the development of new missiles. The missile design method is bound to have significant changes. RSS technology has advantages in raise flying speed, distance and maneuverability. Its application in the design of an air-to-air missile is the objective needs of the new generation missiles, and is also an important way to improve the performance of the new missiles.

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