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ESTIMATED EFFECT ON PROJECTILE FLIGHT STABILITY OF AN INTERIOR CANTILEVER BEAM

Charles H. Murphy

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
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Results of a published theory of the effect of a moving internal part on the angular motion of a spinning projectile are summarized and applied to a projectile with an internal cantilever beam. An example of a 155mm shell is worked out in detail.

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I. INTRODUCTION

In Reference 1, a general theory was developed for predicting the influence of internal component motion on projectile stability. The effect of the center-of-mass motion of a ball rotor in the M505 fuse on the stability of two Army shell was predicted successfully by the theory and it has been recently used in the Air Force development of an improved 20mm projectile. In another application involving the performance of an 8-inch Army projectile, the effect of the forced precession of a spinning component was correctly predicted.

In a recent projectile design, the need for an internal cantilever beam became apparent. Since this beam could have some movement, the designers have expressed concern as to the possibility of flight instability induced by vibrations of this beam. It is the purpose of this report to show how the general theory of Reference 1 can be applied to this problem.

II. GENERAL THEORY

The theory assumes that the only part of the component motion that need be considered is that performed at the circular frequency of the fast mode of the projectile pitching and yawing motion. This component motion can be

(1) a circular motion of the component's center of mass in a plane perpendicular to the projectile's axis (M505 ball rotor);

(2) forced precession of the component's spin axis about the projectile's axis (8-inch projectile); or

(3) a combination of both of these motions.

The center-of-mass motion has a radius ε and a phase angle ϕ_ε with respect to the plane of the angle of attack, while the spin-axis motion has a cone angle γ and a phase angle ϕ_γ with respect to the angle-of-attack plane. The motions are shown to have the following effect on the fast-mode frequency $\dot{\phi}_1$, the fast-mode damping λ_1, and the spin moment M_x.

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1. *C. H. Murphy, "Influence of Moving Internal Parts on Angular Motion of Spinning Projectiles,"* *Journal of Guidance and Control 1, No. 2, March-April 1978, pp. 117-122. (See also BRL MR 2731, AD A037338, February 1977.)*

$$\Delta\dot{\phi}_1 = \frac{-\dot{\phi}_{1r} C_1}{K_1 (2 I_t \dot{\phi}_{1r} - L_{x0})} \qquad (1)$$

$$\Delta\lambda_1 = \frac{\dot{\phi}_1 S_1}{K_1 (2 I_t \dot{\phi}_1 - L_{x0})} \qquad (2)$$

$$\Delta M_x = - \dot{\phi}_1 K_1 S_1 \qquad (3)$$

$$L_{x0} = I_{xb} p + I_{xc} p_c \qquad (4)$$

$$S_1 = (I_{xc} p_c - I_{tc} \dot{\phi}_1)\gamma \sin \phi_\gamma - m_c x_c \dot{\phi}_1 \varepsilon \sin \phi_\varepsilon \qquad (5)$$

$$C_1 = (I_{xc} p_c - I_{tc} \dot{\phi}_1)\gamma \cos \phi_\gamma - m_c x_c \dot{\phi}_1 \varepsilon \cos \phi_\varepsilon \qquad (6)$$

where K_1 is the amplitude of the fast-mode motion

I_{xb}, I_{xc} are spin moments of inertia of the projectile body and component, respectively

I_{tb}, I_{tc} are pitch moments of inertia of the projectile body and component, respectively

$I_x = I_{xb} + I_{xc}$

$$I_t = I_{tb} + I_{tc} + m_b x_b^2 + m_c x_c^2$$

m_b, m_c are the masses of the body and component, respectively

x_b, x_c are the axial distances between the projectile c.m. and the body c.m. or the component c.m.

$\dot{\phi}_{1r}$ is the fast-mode frequency for a rigid projectile ($\gamma = \varepsilon = 0$)

$\dot{\phi}_1$ $\dot{\phi}_{1r} + \Delta \dot{\phi}_1$

p_c is the spin of the component.

It should be noted that the minus signs in Equations (5-6) do not appear in the definitions of S_1 and C_1 in Reference 1. Unfortunately, there is a systematic error in all ϕ_ε relations in Reference 1. It can be corrected, however, by replacing ϕ_ε by $\phi_\varepsilon + 180°$ in all of these relations and this is the cause of the minus signs in Equations (5-6).

III. APPLICATION TO CANTILEVER BEAM

ε and γ can be estimated easily since they are fixed by clearances or by elastic properties of the projectile structure. The phase angles, ϕ_γ and ϕ_ε, depend on friction forces of some kind and are quite difficult to estimate accurately. Upper bounds for the contribution of component motion to the fast-mode damping can be obtained by using the worst possible values of $\sin \phi_\gamma$ and $\sin \phi_\varepsilon$.

To illustrate the use of this theory on a 155mm shell with an internal cantilever beam, we will use the parameters given in Table 1. This 45-kg shell has a 3.4-kg forward-facing cantilever beam whose attachment point is 23 cm forward of the shell center of mass. If we assume the beam has a parabolic deflection in a plane containing the projectile's axis and take γ to be the inclination at its center,

TABLE 1. PARAMETERS OF A HYPOTHETICAL 155MM SHELL

$p = p_c = 660$ rad/s	$\dot{\phi}_{1r} \doteq \dot{\phi}_1 = 62$ rad/s
$I_x = 1500$ km-cm^2	$I_t = 22000$ km-cm^2
$I_{xc} = 2.6$ km-cm^2	$I_{tc} = 68$ km-cm^2
$m_c = 3.4$ kg	$x_c = 31$ cm
$\ell_c = 15$ cm	$d_c = 2.5$ cm
$m_c\, x_c\, \dot{\phi}_1 = 6500$ kg-cm/s	$I_{xc}\, p - I_{tc}\, \dot{\phi}_1 = -2500$ kg-cm^2/s
$\lambda_{1r} = -.13$ 1/s	$2\, I_t\, \dot{\phi}_1 - I_x\, p = 1.74 \times 10^6$ kg-cm^2/s
$p_{CR} = 2500$ 1/s	

$$\gamma = 4\varepsilon/\ell_c \tag{7}$$

$$\phi_\varepsilon = \phi_\gamma \text{ for a forward-facing cantilever}$$

$$= \phi_\gamma + 180^\circ \text{ for a rearward-facing cantilever} \tag{8}$$

where ℓ_c is the length of the beam.

For no internal friction, ϕ_ε should be 180° for positive x_c. An extreme upper bound for the effect of friction would be given by a change in this phase angle of 60°. Thus we will assume ϕ_ε to be 240°. Equation (2) can now be used to give a conservative estimate of the required deflection to change λ_{1r} by 50%. (If x_c were negative, the no friction value of ϕ_ε is 0° and we would assume the friction value to be 60°.)

$$\left(\varepsilon/K_1\right)_{req} = \frac{(|\lambda_{1r}|/2)\ (2\ I_t\ \dot{\phi}_1 - I_x\ p)}{\dot{\phi}_1 \left[\left(I_{xc}\ p - I_{tc}\ \dot{\phi}_1\right)(4/\ell_c) - m_c\ x_c\ \dot{\phi}_1\right] \sin 240^\circ} \tag{9}$$

For our hypothetical shell this yields

$$\left(\varepsilon/K_1\right)_{req} = .30 \text{ cm/rad} \tag{10}$$

A relation between deflection and fast-mode amplitude can be obtained by assuming that the beam deflection can be described by an elastic spring constant k and equating the spring force to the centrifugal force.

$$k\ \varepsilon = m_c\ \dot{\phi}_1^2\ (K_1 |x_c| + \varepsilon) \tag{11}$$

or

$$\varepsilon/K_1 = \frac{|x_c|\dot{\phi}_1^2}{p_{CR}^2 - \dot{\phi}_1^2} \tag{12}$$

where

$$p_{CR} = \sqrt{k/m_c}$$

Equations (10) and (12) show that a p_{CR} of 630 1/s is required for the beam to cause significant instability. Our projectile has a p_{CR} four times larger than this so it can only have trouble if its beam is sixteen times softer than it is.

In summary, then, the theory of Reference 1 can be used to determine the effect on stability of an interior cantilever beam. If rough estimates show a very small effect, a more detailed analysis is unnecessary. In our example this is the case.

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