Technique to Reduce Yaw and Jump of Fin-Stabilized Projectiles

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Nomenclature

A	= cross-sectional area of projectile, m^{-2}
C_D, C_{L_α}, C_{M_α}	= drag, lift, and static moment coefficients
D	= projectile diameter (0.0373 m for DM13)
Iy	= projectile transverse moments of inertia, $kg \cdot m^{-2}$
m	= projectile mass, kg
t	= time, s
V	= velocity, m/s
Δ	= component c.g.-c.p. separation, m
Θ	= trajectory deflection angle, rad
ξ	= yaw angle (o at muzzle, m at first maximum yaw), rad
ρ	= density, kg/m^{-3}

Introduction

MODERN tank-fired kinetic energy munitions use a large-fineness-ratio (>20), fin-stabilized projectile carrying a high-density penetrator. With these long rods, yaw exceeding 1 deg degrades penetration because of interference between the projectile body and the sides of the penetration channel. A second major concern is accuracy. Launch angular motion can produce lateral deviation of the shot line, termed aerodynamic jump,[1] which directly affects round-to-round dispersion.

Because of in-bore and sabot discard disturbances, yaw rates at entry into freeflight of 10 rad/s are possible.[2] As the round moves downrange, the yaw cycle is characterized by successive maxima and minima eventually damping to a small-amplitude, circular limit cycle motion. Maximum yaw can be 5 deg near the gun damping to less than 1 deg by 2 km. To reduce yaw near the weapon, two approaches are plausible: decreasing launch disturbance and improving aerodynamic stability. Both are reflected in the following expression for first maximum of yaw:

$$\xi_m = \left[\frac{-2I_y}{C_{m_\alpha}\rho V^2 DA}\right]^{\frac{1}{2}} \frac{\mathrm{d}\xi_o}{\mathrm{d}t} \tag{1}$$

A decrease in launch disturbance reduces the initial angular rate and produces a corresponding drop in the first maximum of yaw. However, yaw also can be lowered by decreasing the bracketed terms in Eq. (1). In a practical sense, only the moment coefficient can be significantly altered. Changes in nose bluntness, fin planform, fin placement, and number of fins are traditional design approaches to increase stability. This Note describes an alternative that dynamically modifies the projectile geometry in flight.

Concept

The aerodynamic moment is produced by two main lift forces, one on the projectile nose and the other on the projectile fins. The nose lift is destabilizing, and the fins are the major stabilizing surfaces. If the nose lift can be reduced or eliminated, the projectile stability will be increased. One way to reduce nose lift is to increase nose bluntness, but this dramatically increases drag. A possible alternative is to gimbal the projectile nose in a way that allows it to turn into the airstream (Fig. 1). By placing the center of pressure of the nose aft of the pivot bearing, the aerodynamic moment acts to continually align the nose with the flow velocity vector. Thus, the nose attitude is maintained at zero angle of attack and the nose lift is eliminated. Such configurations have been considered in the past. Goddard[3] and Barrett and Stutts[4] use a gimbal nose connected to a set of actuators as a means of steering a flight body. Kranz[5] describes a pintle-mounted free nose conceptually like that proposed here; however, no analytic or test results are presented.

It is possible to estimate the effect of perfect nose alignment to the freestream on the moment coefficient. In these considerations, a 120-mm DM13 projectile is used as a baseline. The moment coefficient is measured in the U.S. Army Research Laboratory Transonic Range and for this simple analysis is assumed to be the sum of two components, nose and tail lift:

$$C_{M_\alpha} = -(\Delta_t/D)C_{L_{\alpha_t}} + (\Delta_n/D)C_{L_{\alpha_n}} = -16.5 \tag{2}$$

according to slender body theory, the nose normal force is

$$C_{N_\alpha} \cong C_{L_\alpha} = 2.0 \tag{3}$$

which acts at the center of pressure of the projectile nose a distance of roughly 200 mm from the center of gravity; thus, the moment coefficient with zero nose lift is estimated as

$$C_{M_\alpha} = -16.5 - (\Delta_n/D)C_{L_{\alpha_n}} = -27.4 \tag{4}$$

The change from −16.5 to −27.4 is a significant enhancement (66%) of the moment coefficient. Because the first maximum yaw varies inversely with the square root of the moment coefficient [Eq. (1)], yaw with the gimbal nose would be 22% lower than for the rigid projectile given identical launch angular rates. Note that yaw damping also depends on the lift components of the nose and tail. If the nose lift is eliminated, yaw damping is decreased.

The effect of angular rate on trajectory deflection is expressed as the aerodynamic jump[1]:

$$\Theta = \frac{-I_y}{mDV}\frac{C_{L_\alpha}}{C_{M_\alpha}}\frac{\mathrm{d}\xi_o}{\mathrm{d}t} \tag{5}$$

The jump varies directly with lift coefficient and inversely with moment coefficient; therefore, the gimbal nose should show a dramatic decrease in jump. Using the same logic, the lift coefficient for the standard DM13 is

$$C_{L_\alpha} = C_{L_{\alpha_t}} + C_{L_{\alpha_n}} = 7.7 \tag{6}$$

and for the case of the gimbal nose

$$C_{L_\alpha} = 7.7 - C_{L_{\alpha_t}} = 5.7 \tag{7}$$

Using the estimated coefficients for equal angular rates, the gimbal nose has 55% less aerodynamic jump than the rigid projectile.

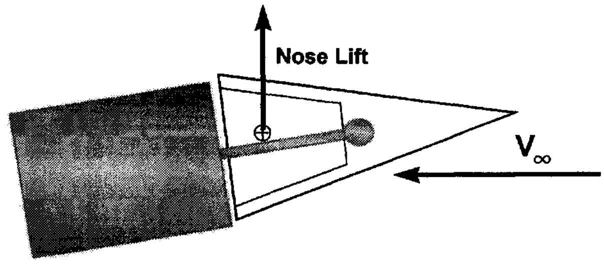

Fig. 1 Gimbal nose.

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Table 1 Experimental coefficients measured in the U.S. Army Research Laboratory Transonic Range

	C_{D_0}	$C_{D^2_\delta}$	C_{L_α}	C_{M_α}
DM13 standard	0.31	6.3	7.7	−16.5
DM13 gimbaled	0.35	13.7	6.8	−20.0

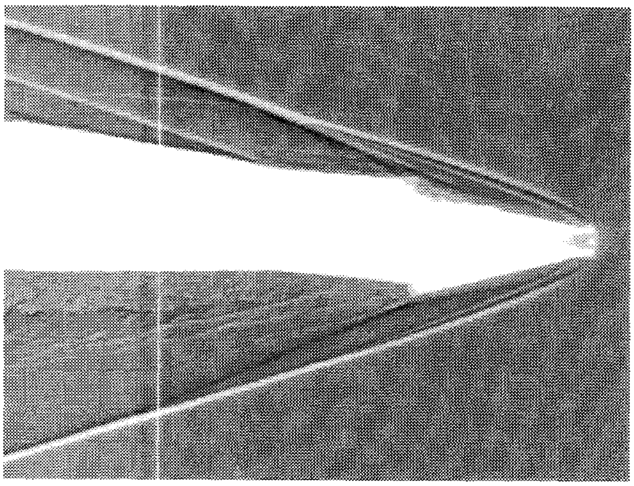

Fig. 2 Spark shadowgraph of gimbal nose projectile at entry to transonic range.

Experiment

A series of experiments was performed to explore nose functioning and measure resulting aerodynamics. A 120-mm DM13 kinetic energy projectile was modified with a gimbal nose. Because the gimbal is supported on a stanchion, the maximum free rotation of the nose is limited to 10 deg, which is less than the maximum yaw expected. Six of these rounds were built and fired through the U.S. Army Research Laboratory Transonic Range. All of the projectiles survived launch with the gimbal noses intact; however, some separation was observed between the base of the cone and the forward shoulder of the projectile. This separation may affect the aerodynamics of the round, particularly the drag. The gimbal nose did function as intended. This is illustrated by the spark shadowgraph in Fig. 2. The projectile body clearly has appreciable yaw while the nose is turned into the flow.

A comparison of the aerodynamic coefficients with and without the gimbal nose is presented in Table 1. These measurements have 5–10% accuracy for zero yaw drag and static moment and 10–20% accuracy for lift and drag due to yaw.[6] The two drag terms represent the zero yaw drag and drag associated with yaw. The gimbal nose projectile has 13% greater zero yaw drag than the standard DM13. This may reflect the influence of the nose separation after launch. The drag associated with yaw is significantly higher for the gimbal case. This may be attributable to the formation of strong shocks off the projectile shoulder as it is uncovered in the yawed state (Fig. 2). However, when multiplied by the yaw squared, this drag component is an order of magnitude smaller than the zero yaw drag. As the round moves downrange, the yaw damps and this effect becomes even less important.

The lift and moment coefficients show the same trend as predicted by the simple estimates in the preceding section. The magnitude of the difference between standard and gimbal nose is less than predicted, which may be associated with both the crudeness of the estimate technique and the effects of nose standoff after launch. Even with these values, it would be expected that for the same launch yaw rate the gimbal nose would show 10% less maximum yaw and 28% less aerodynamic jump than the standard round.

Conclusions

A technique is examined to reduce the nose lift on fin-stabilized projectiles. Potential advantages of the technique include reducing first maximum yaw and aerodynamic jump. Experimental results fell short of simplistic estimates but showed worthwhile improvement in flight characteristics. It is necessary to further improve the design to reduce separation between the nose and the projectile associated with decompression upon release from the gun. The benefit of a fully functional design would then have to be weighed against the additional complexity and cost of the finished projectile.

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Risk Assessment Consequences of the Lognormal Distribution of Midtropospheric Wind Changes

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Introduction

A RECENT study showed that the vector magnitude of wind changes in the region between 6- and 17-km altitude is lognormally distributed.[1] The study was limited to the winter season over the Kennedy Space Center (KSC) and encompassed wind changes over periods of 0.25, 1, 2, and 4 h. The measurements were made using the 50-MHz Doppler Radar Wind Profiler (DRWP) at KSC as described by Wilfong et al.[2] The winter season was selected because climatology suggested that the largest wind changes would be observed then. The altitude and time envelopes were selected on the basis of the region of greatest interest to the Shuttle and Titan launch communities for ascent loads. This Note examines the consequences of the lognormality of the wind-change distribution for risk analysis of launch wind changes. It does not address the associated problem of risk analysis of vehicle loads because loads are related to the winds in a highly nonlinear and vehicle-specific way.

Lognormal Distribution

A variable y is lognormally distributed if it is related to a normally distributed (Gaussian) variable x having mean M and standard deviation S, such that

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