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AEROBALLISTICS OF CORKSCREW PROJECTILES,

JUN 1978

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1. INTRODUCTION

During the development and exploitation of the BRL Non-Conical Boattail Projectile (1-5), it became evident that a new projectile shape which combines a triangular nose with a triangular boattail (Figure 1) would have low drag and a long wheel base for low balloting in the gun barrel. No aerodynamic data were available on the configuration (nicknamed the corkscrew) at the beginning of this program, so it was deemed advisable to conduct wind tunnel and range tests to determine its drag and stability characteristics.

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Figure 1. The Corkscrew Projectile

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2. THE CORKSCREW GEOMETRY

The basic corkscrew geometric pattern is obtained by cutting a solid cylinder with a series of six skewed planes to obtain the configuration shown in Figure 1. Three skewed planes form the pointed triangular nose and with three skewed planes, sloped the opposite way, to form the boattail. The boattail planes up to now have been terminated when they form an inscribed triangle, but it is possible to terminate them at any desired axial station. The slope or angle of these planes with respect to the cylinder centerline can be varied; however, the angles of the three nose planes must be the same as well as the angles of the three boattail planes. However, the nose plane angles need not be the same as the boattail plane angles. The six planes are usually skewed at a constant twist rate generally near the spin expected at launch.

The corkscrew configuration does not have the usual axial symmetry and, therefore, it can be expected to have non-linear aerodynamic characteristics, especially at spins ($\rho d/V$) far from the configuration twist. For this reason, the spin of all of the range flights made to date have been near the twist of the configuration.

3. TEST RESULTS

The first data came from supersonic wind tunnel tests of a 5-caliber long non-interdigitated or non-overlapping configuration (Figure 2). This configuration has a 10° nose angle and a 7° boattail and the model is 5.715 cm in diameter. The significant results from these tests are described below and are compared with results from the 5-caliber Army-Navy Spinner Rocket (ANSR) with a cylindrical tail.

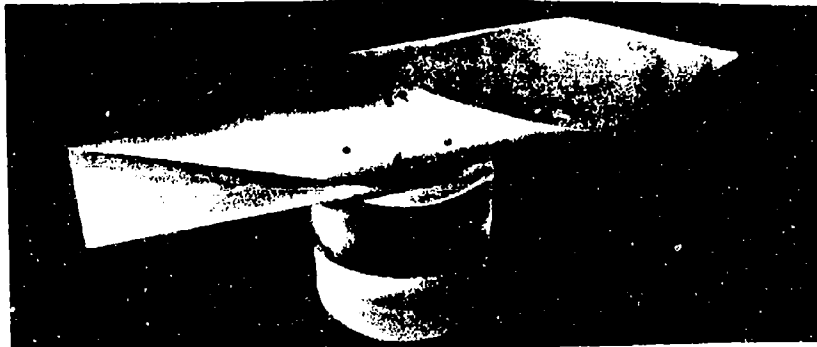


Figure 2. The 5-Caliber Wind Tunnel Model of the Corkscrew Projectile

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(a) Even though the normal force on the corkscrew is extremely high (Figure 3), the pitching moments about a center of gravity three-calibers aft of the nose are about the same as those on the 5-caliber ANSR (Figure 4). Therefore, the normal force center of pressure of the corkscrew configuration is located further aft than on the 5-caliber ANSR.

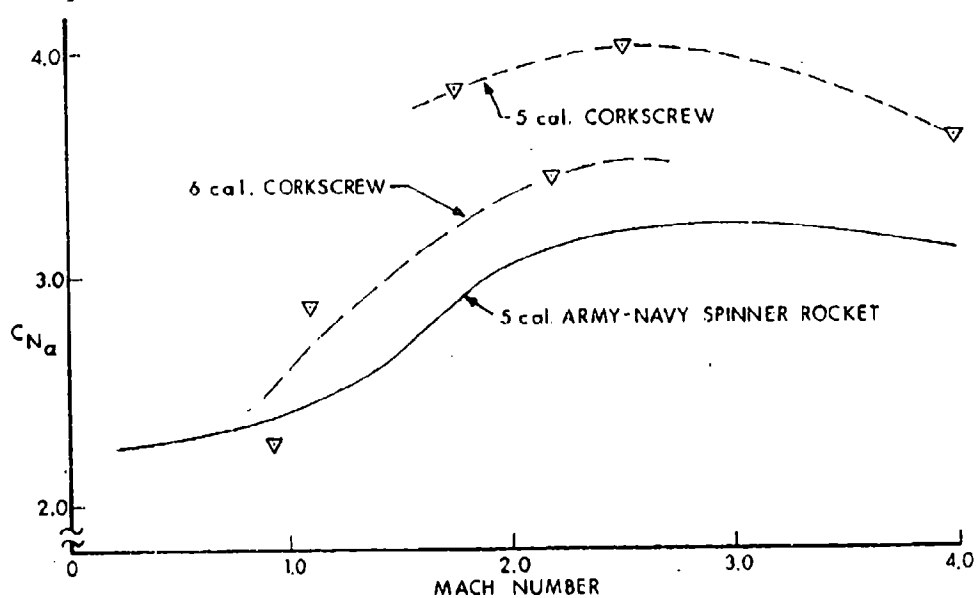


Figure 3. The Normal Force Coefficient of the Corkscrew Projectile

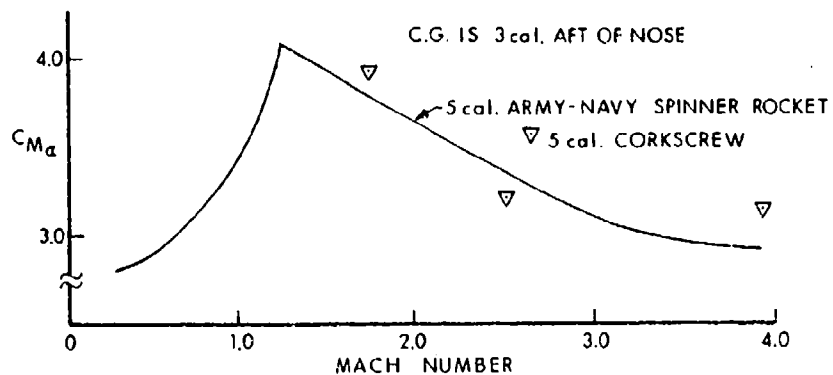


Figure 4. The Pitching Moment Coefficient of the Corkscrew Projectile

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(b) At low angles of attack, the Magnus forces and moments are small at all spin rates near the configuration twist. This is due to the zero spin "offsetting" side force and moment characteristic of this configuration⁽²⁾ (Figure 5).

Because of the difficulty in designing and building the interdigitated wind tunnel version, 20 mm diameter 6-caliber and 8-caliber long models were built for flights in the BRL Aerodynamics Range. The models were made of brass and used drilled base holes to increase the possibility of stable flights in the range. The 6-caliber long models had 7° triangular boattails and 5.71° triangular noses while the 8-caliber long models had 4.76° on both nose and boattail planes. Both the 6-caliber and 8-caliber configuration had one-caliber overlap between the nose and boattail planes. Below, aerodynamic data from several flights up to $M = 2.2$ are compared with aerodynamic data on the 5.7-caliber long M549 (Figure 6) and the 6.2-caliber long non-conical boattail projectile-A (Figure 7).

(1) Shock waves or flow discontinuities on the corkscrew configuration are virtually non-existent at transonic speeds (Figure 8). This figure can be compared to the shock wave pattern existing on a conventional projectile configuration at the same Mach number (Figure 9). The almost shock free flow pattern is believed to be due to the more uniform area distribution of the corkscrew configuration (Figure 10). Further studies in both ranges and wind tunnels would be necessary to completely understand and explain this phenomenon.

(2) The drag coefficient of the corkscrew configuration is very low compared to that of the two reference projectiles (Figure 11).

(3) The normal force coefficient (Figure 12) is not as large as for the non-interdigitated wind tunnel configuration, but it is larger than for the M549 and the NCB-A projectiles.

(4) Even with the rearward center of gravity of the corkscrews, the pitching moment coefficient is much lower for the 6-caliber corkscrew (Figure 13) than for the M549 and NCB-A projectiles. The pitching moment coefficient of the 8-caliber corkscrew is just slightly higher than the maximum pitching moment coefficient of the M549. The pitching moment coefficient of the corkscrew appears to remain nearly constant with Mach number indicating that the corkscrew configuration does not have the characteristic spike in the pitching moment curve. Additional data above $M = 1.05$ are required to verify this.

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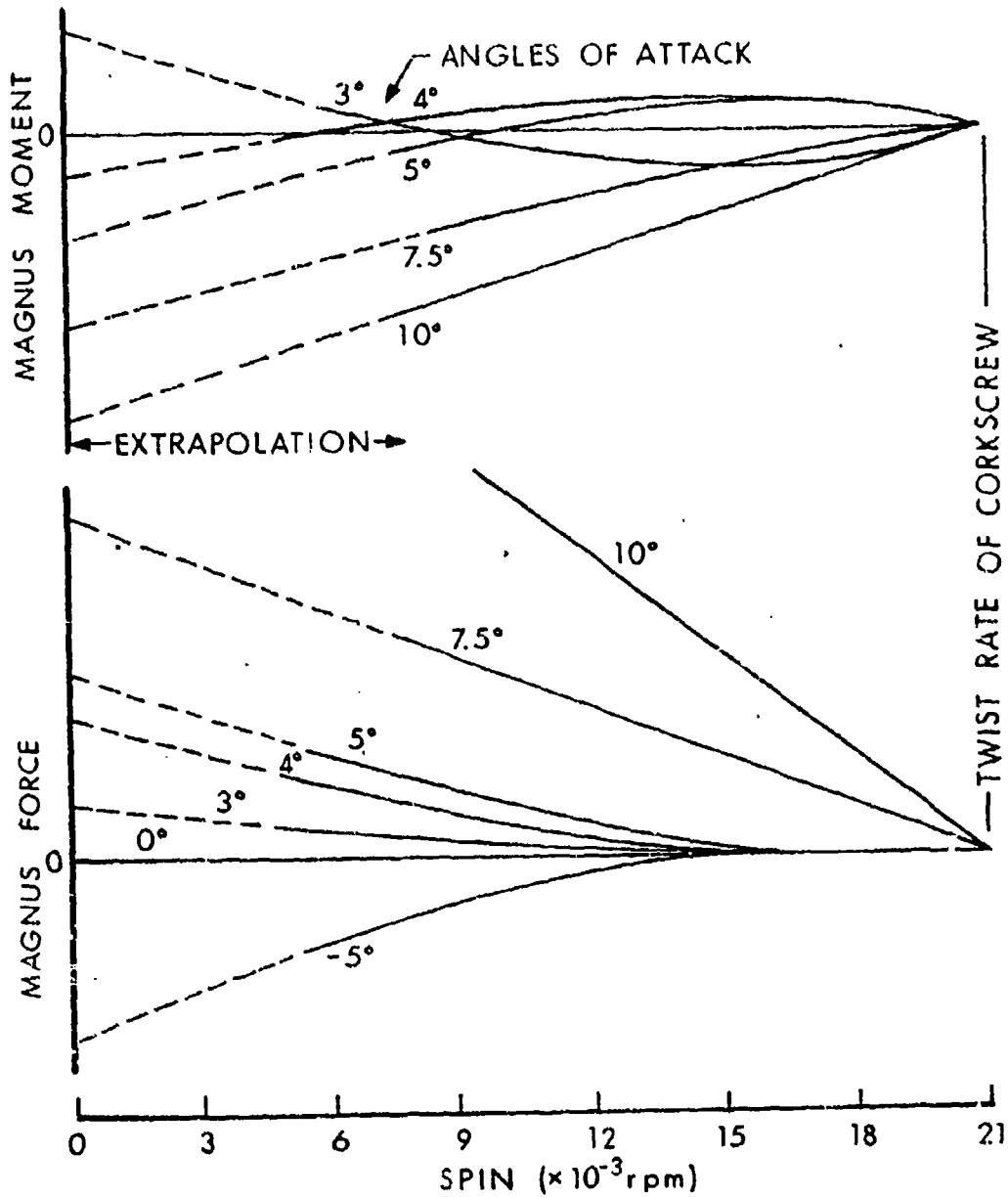
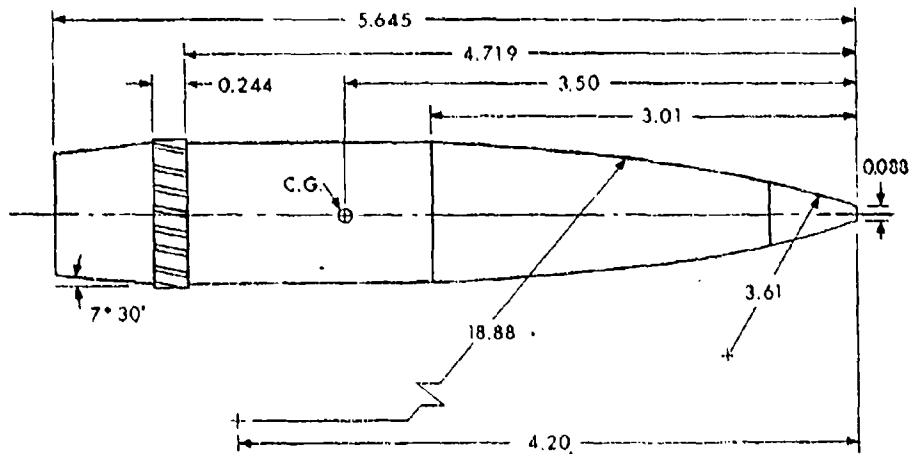


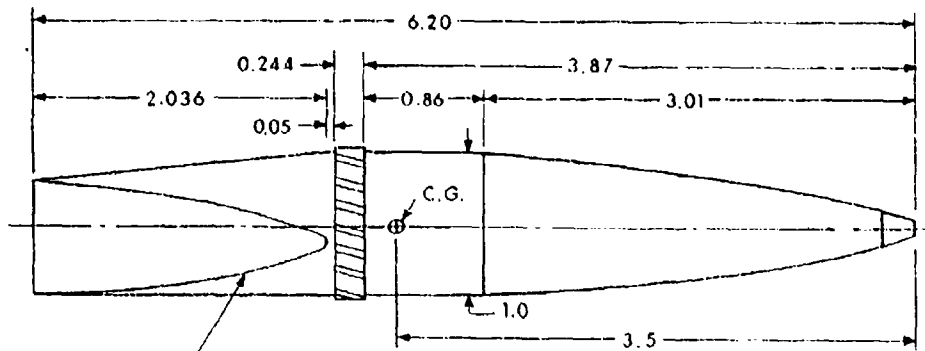
Figure 5. The Approximate Magnus Characteristics of the Corkscrew Projectile

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ALL DIMENSIONS IN CALIBERS
1 CALIBER = 154.7mm

Figure 6. The 155 mm M549 Projectile



7° TRIANGULAR BOATTAIL
R.H. SPIRAL - 1 TURN IN
20 CALIBERS

ALL DIMENSIONS IN CALIBERS
1 CALIBER = 154.7mm

THIS CONFIGURATION IS THE SAME
AS THE M549 FORWARD OF THE
ROTATING BAND

Figure 7. The Non-Conical Boattail Projectile NCB-A

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Figure 8. A Shadowgraph of a Corkscrew Projectile
Flying at $M = .92$



Figure 9. A Shadowgraph of a Conventional Projectile
Flying at $M = .92$

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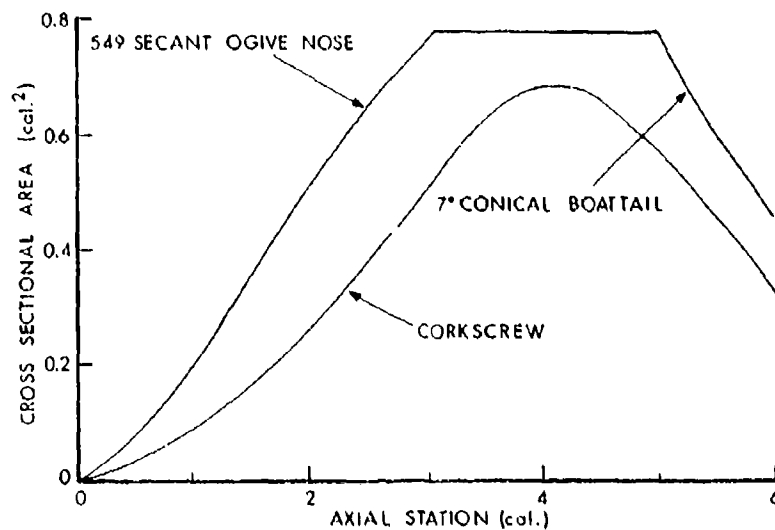


Figure 10. The Area Distribution of a Corkscrew Projectile Compared to a Conventional Projectile

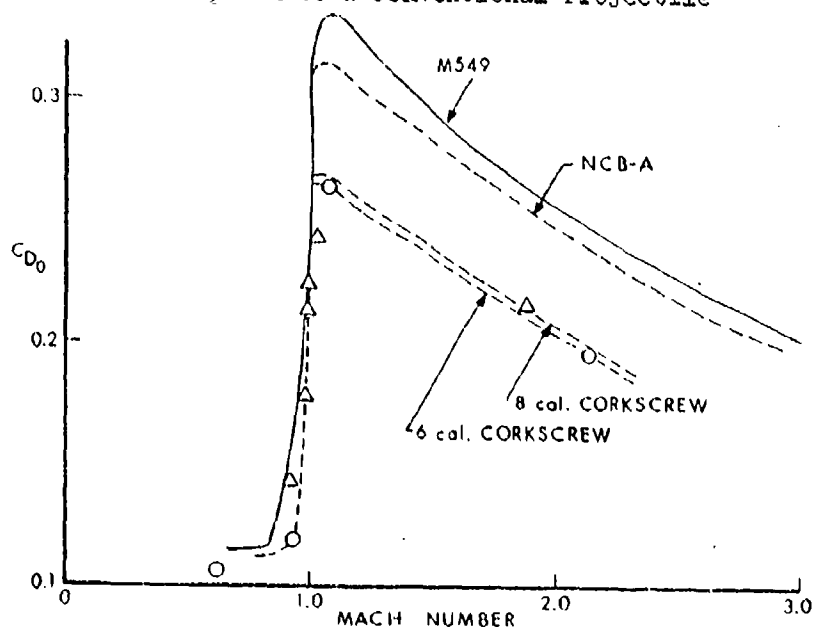


Figure 11. The Drag Coefficient of a Corkscrew Projectile Compared to Other Projectiles

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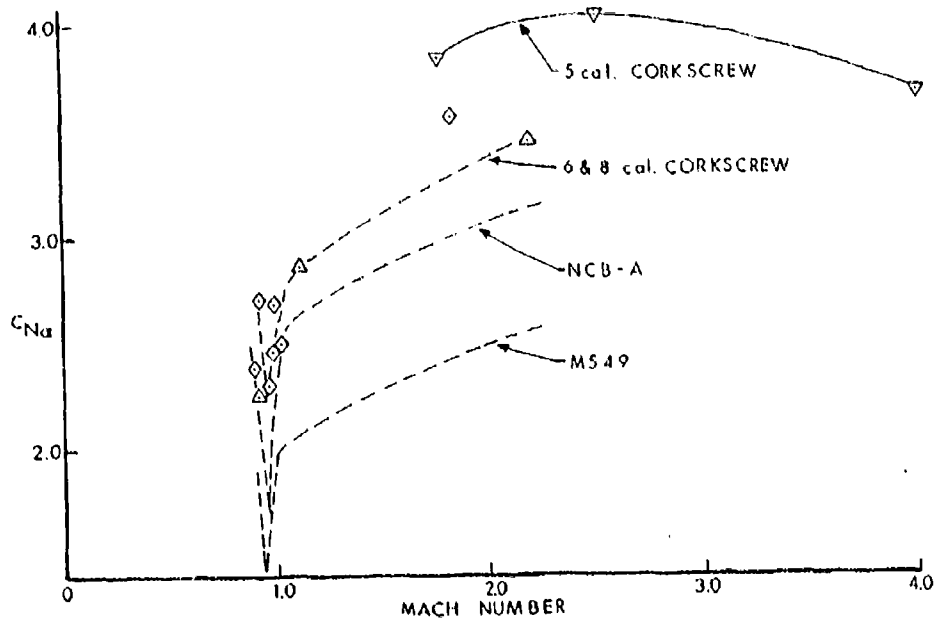


Figure 12. The Normal Force Coefficient of the Corkscrew Projectile Compared to Other Projectiles

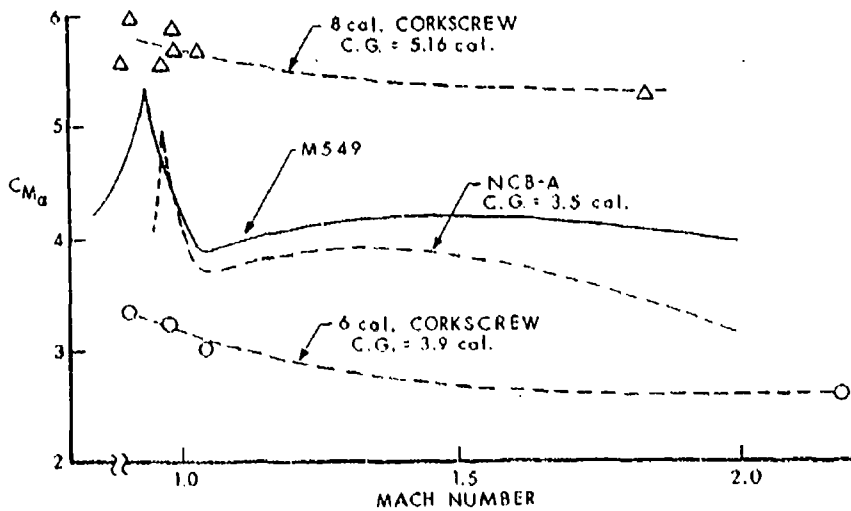


Figure 13. The Pitching Moment Coefficient of the Corkscrew Projectile Compared to Other Projectiles

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(5) Efforts to fly corkscrews at higher Mach numbers have so far failed due to excessive loads on the model nose during launch. Various launching techniques are being tried to overcome this problem.

4. EXTRAPOLATION TO LONGER LENGTH PROJECTILES

The aerodynamic data obtained on the corkscrew configurations indicate that longer configurations of this shape can be flown with satisfactory stability. The implication is that the corkscrew will permit the use of much longer, incaliber, spin-stabilized, low drag, projectiles.

Calculation of possible projectile lengths have been made and the results are shown in Table I. For the calculation of the moments of inertia, it was assumed that the corkscrew configuration has equal angles for the nose and tail "flats", that the nose and tail overlap by one-caliber and that the projectile is made of a homogeneous material with a density of 9 gms/cc. Using the obtained values for the 6-caliber and 8-caliber corkscrews, the normal force and pitching moment coefficients for longer configurations have been estimated at Mach 2.1 (Table I).

From these assumptions and calculations, the gyroscopic stability factor has been calculated. This calculation indicates that an 11-caliber corkscrew made of a homogeneous material with a density of 9 gms/cc can be flown with satisfactory stability if the spin is at least one revolution per fifteen calibers of forward travel.

5. APPLICATIONS FOR THE CORKSCREW SHAPE

Besides being an excellent aerodynamic reference shape, the corkscrew configuration may have application as a spin stabilized, kinetic energy penetrator. The corkscrew's low drag will provide low velocity deceleration between the gun and the target, and its' low pitching and Magnus moments will provide good stability for long (l/d) penetrator configurations. In small caliber sizes (20 to 40mm) the whole, high density penetrator might have the corkscrew exterior shape, while in larger calibers (105 to 120mm) the penetrator rod could be submerged in the corkscrew carrier. Both full bore and subcaliber configurations are feasible. A sabot for a corkscrew projectile can be a simpler and lighter weight configuration than the sabots now used on conventional, axisymmetric projectiles. The BRL is presently studying the feasibility of these concepts.

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Table I. Physical and Aerodynamic Characteristics

| z/d | 6 | 7 | 8 | 9 | 10 | 11 |
|---------------------------|------|-------|-------|-------|-------|-------|
| Vol/ r^3 | 18.0 | 21.5 | 24.9 | 28.4 | 31.9 | 35.4 |
| C.G. | 3.90 | 4.53 | 5.16 | 5.79 | 6.43 | 7.06 |
| $I_{y_{C.G.}} / \rho r^5$ | 91.2 | 151.2 | 233.0 | 339.9 | 458.9 | 624.5 |
| k_y | 1.13 | 1.33 | 1.53 | 1.73 | 1.90 | 2.10 |
| $I_x / \rho r^5$ | 6.48 | 7.85 | 9.23 | 10.60 | 11.97 | 13.35 |
| k_x | .300 | .302 | .304 | .305 | .306 | .307 |

For Mach Number = 2.1 and Spin = 1/15 cal.

| | | | | | | |
|----------------------------|------|--|------|--|------|------|
| C_{N_α} (estimated) | 3.4 | | 3.4 | | 3.2 | 3.2 |
| C_{m_α} (estimated) | 2.58 | | 4.08 | | 5.69 | 6.28 |
| S_ξ | 3.73 | | 2.27 | | 1.39 | 1.15 |

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