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Aerodynamic Properties
Of 60-MM Mortar Shell, T24

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DEPARTMENT OF THE ARMY PROJECT No. 5B03-03-001
ORDNANCE RESEARCH AND DEVELOPMENT PROJECT No. TB3-0108
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND
AERODYNAMIC PROPERTIES OF 60-MM MORTAR SHELL, T24

Eugene D. Boyer

Department of the Army Project No. 5803-03-001
Ordnance Research and Development Project No. TB3-0108

ABERDEEN PROVING GROUND, MARYLAND
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AERODYNAMIC PROPERTIES OF 60-MM MORTAR SHELL, T24

ABSTRACT

The spin histories, drag, and yaw properties of the 60-mm T24 mortar shell are presented. These data were obtained from Transonic Range firings.
TABLE OF SYMBOLS AND COEFFICIENTS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>A</td>
<td>axial moment of inertia</td>
</tr>
<tr>
<td>B</td>
<td>transverse moment of inertia</td>
</tr>
<tr>
<td>cm</td>
<td>center of mass</td>
</tr>
<tr>
<td>d</td>
<td>diameter</td>
</tr>
<tr>
<td>M</td>
<td>Mach number</td>
</tr>
<tr>
<td>K_D</td>
<td>drag coefficient</td>
</tr>
<tr>
<td>K_M</td>
<td>moment coefficient</td>
</tr>
<tr>
<td>K_MA</td>
<td>moment coefficient due to cross acceleration</td>
</tr>
<tr>
<td>K_L</td>
<td>lift coefficient</td>
</tr>
<tr>
<td>K_H</td>
<td>damping coefficient</td>
</tr>
<tr>
<td>( \phi' )</td>
<td>roll rate (deg./ft.)</td>
</tr>
<tr>
<td>( \lambda_{1,2} )</td>
<td>yaw damping rates</td>
</tr>
<tr>
<td>( \sin )</td>
<td>sine of the angle of yaw</td>
</tr>
<tr>
<td>( \frac{s^2}{s_e^2} )</td>
<td>mean squared yaw</td>
</tr>
<tr>
<td>( s_e^2 )</td>
<td>effective squared yaw for ( K_M )</td>
</tr>
<tr>
<td>( C_{L_\psi} )</td>
<td>roll moment derivative due to canted surface</td>
</tr>
<tr>
<td>( C_{L_\rho} )</td>
<td>roll moment derivative due to rolling velocity</td>
</tr>
<tr>
<td>( \rho )</td>
<td>density of air</td>
</tr>
<tr>
<td>( \mu )</td>
<td>total velocity</td>
</tr>
</tbody>
</table>
INTRODUCTION

In connection with a mortar project of the research division of the Bud Company, Picatinny Arsenal requested that the Ballistic Research Laboratories study the aerodynamic properties, particularly roll, of the 60-mm T24 mortar shell. The shell was tested with three different fin assemblies: non-canted fins, fins with two degrees of cant on the after section, and fins with four degrees of cant on the after section (Figure 7a). The firings were conducted in the Transonic Range. This report is a brief account of the firings and the results obtained.

EXPERIMENTAL PROCEDURE

The shells were launched from a trigger-fired 60-mm mortar tube mounted in a 105-mm howitzer field mount (Figure 7b). At normal velocities and the elevation angles necessary to fire through the Transonic Range instrumentation the mortar shell would hit within the range building. Hence it was necessary to fire the program from within the range building and forego some of the instrumentation. For the shell to enter the instrumentation, it was necessary to start its flight approximately nine feet above the range floor. To obtain this height, the field carriage was loaded in the rear of a 2-1/2 ton shop truck (Figure 8) and the program fired from a point between the first two groups of range stations. As a result only twenty of the twenty-five spark photographic stations could be utilized. Timing cables were rear-ranged to permit thirteen time-of-flight measurements to be taken.

To determine the roll histories of the shell, sets of three yaw cards were placed at the beginning and end of the shadowgraphic instrumentation. The shells were equipped with two "pop-out" pins which remained within the shell's contour during launching and emerged when the projectile entered free flight. The pins extended beyond the major diameter and cut the yaw cards. From these cuts the roll history of the projectile was determined. To extend the roll measurements to longer ranges (1800 feet) it was necessary to fire a few rounds outdoors. The higher angle trajectories required for the longer ranges could not be fired from inside the range building.
Ninevent rounds were fired through the range and eleven outdoors. All of the rounds were fired at a nominal velocity of 500 fps. Twelve of the nineteen shell fired through the range had trajectories suitable for determining aerodynamic data. Roll data at 1800 feet were obtainable from only four of the eleven shell fired outside the range. A sketch of the shell and its physical measurements are given in Figure 6.

EXPERIMENTAL RESULTS

A. Drag

The drag coefficient does not appear to be noticeably affected by the presence of different fin cents. Any differences that may exist are well within the scatter of drag data expected from round to round variation with production shell. However, a definite variation of drag with yaw level is evident (Figure 1) and, fitting a least squares to

\[ \frac{K_D}{K_{D0}} + K_{D2} \theta^2 \]

yields:

\[ K_{D0} = 0.0761 \pm 0.0008 \]

\[ K_{D2} = 2.1 \pm 0.4 \]

where \( \theta \) is in radians. All errors are standard errors.

B. Yawing Motion

The values of the yaw properties for each round are given in Table 1. As seen in Figures 2 and 3 the moment coefficient, \( K_M \), and the lift coefficient, \( K_L \), are influenced by the magnitude of the yaw. These coefficients have been reduced to zero-yaw values by the relationships:

\[ K_M = K_{M0} + K_{M2} \theta^2 \]

\[ K_L = K_{L0} + K_{L2} \theta^2 \]

where

\[ M = \rho d \theta^3 \left[ K_{M0} + K_{M2} \theta^2 \right] \theta \]
\[
\text{lift force} = c_1^2 \mu^2 \left[ K_{10} + K_{10} s e^2 \right] 5
\]

and \( s e^2 \) is a function of the amplitude of the two yaw components and the rates as defined in the Table of Symbols and Coefficients. In Reference 4 it is shown that if non-linearities in aerodynamic forces and moments are representable by cubics in yaw, then \( K_M \) vs. \( s e^2 \) and \( K_L \) vs. \( K_{10}^2 + K_{20}^2 \) form linear combinations.

Fitting by least squares gives: *

\[
\begin{align*}
K_M &= -0.84 \pm 0.02 \\
K_{10} s e^2 &= -10 \pm 2 \\
K_{20} &= 0.91 \pm 0.04 \\
K_{20} s e^2 &= 18 \pm 5 \\
\end{align*}
\]

when yaw is expressed in radians.

The yaw damping coefficient, \( K_H - K_{MA} \) was poorly determined due to the presence of small asymmetries in the shell and no correlation with yaw was apparent. A value of \( K_H - K_{MA} = 8.0 \) seems representative of this shell. The amplitude of yaw damps fifty per cent in approximately two cycles of yaw, a distance of 300 feet.

C. Roll

The roll data, as determined from yaw card measurements, are given in Table 2 and Figures 4 and 5. Slight inconsistencies in performance from round to round, as shown in Table 2, are probably due to minor fin misalignments and manufacturing variations in the cents of the trailing edges of the fins. Yaw card measurements for the shell with the un-canted fins indicated that the shell were not spinning significantly.

* Tricycle rounds were not included in fitting \( K_r \).
The differential equation of motion of a rolling finned missile for a range trajectory is of the form: 

\[ \ddot{\theta} + C_1 \dot{\theta} = C_2 \]

The constants were determined from fitting the yaw card measurements and are:

- 2° cant: 
  \[ C_1 = 0.0014 \text{ (l/ft)} \]
  \[ C_2 = 0.007 \text{ (l/ft}^2) \]

- 4° cant: 
  \[ C_1 = 0.0017 \text{ (l/ft)} \]
  \[ C_2 = 0.017 \text{ (l/ft}^2) \]

Nominally, \( C_1 \) should be the same for missiles differing only in fin cant and \( C_2 \) should be proportional to the cant. The given \( C_1 \)'s are essentially equal, within the significance of the determination, and in the same sense (on a per degree of cant basis) so are the \( C_2 \)'s. Average values would be:

\[ C_1 = 0.00155 \text{ (l/ft)} \]
\[ C_2 = 0.004 \text{ (l/ft}^2) \text{ per degree of cant.} \]

If one assumes the canted area of the fins to be one-tenth of the total fin area, where the fin area is approximately 2.07 square inches, the aerodynamic coefficients\(^1\) for the 4° degree canted fin are:

\[ C_{L_\phi} = .30 \]
\[ C_{L_p} = -.21. \]

---

\(^{1}\)EUGENE D. BOYER

EUGENE D. BOYER
### APPENDIX A

#### TABLE 1

Aerodynamic Data

<table>
<thead>
<tr>
<th>Round Number</th>
<th>Fin Cant.</th>
<th>$K_B$</th>
<th>$K_N$</th>
<th>$K_F$</th>
<th>$\alpha_1 \times 10^5$</th>
<th>$\alpha_2 \times 10^5$</th>
<th>$S_e \times 10^2$</th>
<th>$S_e^2 \times 10^2$</th>
<th>$K_{10}$</th>
<th>$K_{20}$</th>
<th>$K_{30}$</th>
<th>$N$</th>
<th>$S_L$</th>
<th>$S_y$</th>
<th>$S_8$</th>
<th>$d_1$</th>
<th>$C_2^<em>$$^</em>$</th>
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<tr>
<td>3599</td>
<td>$0^\circ$</td>
<td>.424</td>
<td>.0814</td>
<td>.090</td>
<td>.24</td>
<td>.24</td>
<td>.38</td>
<td>.53</td>
<td>4.22</td>
<td>.22</td>
<td>.23</td>
<td>15</td>
<td>8.03</td>
<td>12</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3600$^*$</td>
<td>$0^\circ$</td>
<td>.426</td>
<td>.0802</td>
<td>.816</td>
<td>.25</td>
<td>.13</td>
<td>.009</td>
<td>.059</td>
<td>17</td>
<td>8.02</td>
<td>.015</td>
<td>15</td>
<td>.006</td>
<td>-2.21</td>
<td>2.21</td>
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<tr>
<td>3601$^*$</td>
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<td>.426</td>
<td>.0789</td>
<td>.819</td>
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<td>.13</td>
<td>.009</td>
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<td>.006</td>
<td>-2.21</td>
<td>2.21</td>
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<tr>
<td>3602$^*$</td>
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<td>.0773</td>
<td>.934</td>
<td>.49</td>
<td>.62</td>
<td>.040</td>
<td>.050</td>
<td>.007</td>
<td>8.03</td>
<td>.006</td>
<td>15</td>
<td>.006</td>
<td>-2.33</td>
<td>2.38</td>
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<td></td>
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<tr>
<td>3603$^*$</td>
<td>$0^\circ$</td>
<td>.429</td>
<td>.0794</td>
<td>.959</td>
<td>.91</td>
<td>6.02</td>
<td>.011</td>
<td>.016</td>
<td>13</td>
<td>9.01</td>
<td>.007</td>
<td>15</td>
<td>.006</td>
<td>-2.23</td>
<td>2.43</td>
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<tr>
<td>3594</td>
<td>$2^\circ$</td>
<td>.428</td>
<td>.0825</td>
<td>.870</td>
<td>.32</td>
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<td>3595</td>
<td>$2^\circ$</td>
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<td>.0818</td>
<td>.898</td>
<td>.95</td>
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<td>2.19</td>
<td>.24</td>
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<tr>
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<td>.0816</td>
<td>.936</td>
<td>.96</td>
<td>7.6</td>
<td>.72</td>
<td>2.69</td>
<td>.47</td>
<td>.62</td>
<td>.059</td>
<td>19</td>
<td>.009</td>
<td>-2.40</td>
<td>2.36</td>
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<td></td>
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<td>3598</td>
<td>$4^\circ$</td>
<td>.434</td>
<td>.0840</td>
<td>.924</td>
<td>.93</td>
<td>8.0</td>
<td>.77</td>
<td>3.90</td>
<td>.43</td>
<td>.61</td>
<td>.057</td>
<td>16</td>
<td>.005</td>
<td>-2.41</td>
<td>2.35</td>
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<td></td>
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<tr>
<td>3599</td>
<td>$1^\circ$</td>
<td>.434</td>
<td>.0840</td>
<td>1.071</td>
<td>1.12</td>
<td>7.4</td>
<td>1.32</td>
<td>2.14</td>
<td>1.38</td>
<td>2.14</td>
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<td>15</td>
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<tr>
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<td>.0947</td>
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<td>1.12</td>
<td>7.4</td>
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<td>2.14</td>
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<td>15</td>
<td>.008</td>
<td>-2.61</td>
<td>2.49</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^*$ Tricycle yaw reductions were required on these rounds

- $K_{10}$ size of nutational yaw arm at mid-range
- $K_{20}$ size of precessional yaw arm at mid-range
- $K_{30}$ size of tricycle yaw arm at mid-range
- $N$ number of yaw stations
- $N_r$ number of timing stations

$S_L$ radius of yaw at mid-range

$S_y$ error in yaw fit

$S_8$ error in yaw fit

$\delta_1$ turning rate of nutational arm

$\delta_2$ turning rate of precessional arm
### Table 2

Roll Data (deg/ft)

<table>
<thead>
<tr>
<th>Distance Down Range (ft)</th>
<th>Roll Rate for Various Rounds</th>
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<tr>
<td></td>
<td>Fin Cant 2°</td>
</tr>
<tr>
<td></td>
<td>3594</td>
</tr>
<tr>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td>50</td>
<td>.4</td>
</tr>
<tr>
<td>335</td>
<td>1.3</td>
</tr>
<tr>
<td>615</td>
<td>2.6</td>
</tr>
<tr>
<td>630</td>
<td>2.6</td>
</tr>
<tr>
<td>680</td>
<td>2.6</td>
</tr>
<tr>
<td>725</td>
<td>2.9</td>
</tr>
<tr>
<td>740</td>
<td>3.0</td>
</tr>
</tbody>
</table>

|                          | Fin Cant 4°                   |
|                          | 3588 | 3589 | 3590 | 3591 | 3593 | Field Firings |
| 35                       | .1   | .6   | .3   | .2   | 0    |
| 50                       | .2   | .3   | .3   | .5   | .3   |
| 335                      | 2.3  | 2.4  | 2.0  | 2.8  | 3.4  |
| 615                      | 4.0  | 4.5  | 3.7  | 4.1  | 6.0  |
| 630                      | 4.3  | 4.6  | 3.7  | 5.0  | 6.1  |
| 680                      | 4.9  | 4.9  | 3.8  | 4.9  | 6.6  |
| 725                      | 5.0  | 5.0  | 4.0  | 5.1  | 6.8  |
| 740                      | 5.2  | 5.3  | 4.5  | 4.5  | 6.9  |

1775                      | 12.8 |
1790                      | 14.3 | 14.3
APPENDIX B

Graphs and Photographs

Figure 1 - Drag Coefficient vs. Mean Squared Yaw
Figure 2 - Moment Coefficient vs. $b_e^2$
Figure 3 - Lift Coefficient vs. $K_1^2 + K_2^2$
Figure 4 - Roll Rate vs. Distance Down-Range, Fin-Cant 2°
Figure 5 - Roll Rate vs. Distance Down-Range, Fin-Cant 4°
Figure 6 - Sketch of Shell, 60-mm Mortar Shell T24
Figure 7a - Shell with Non-Canted Fins, 2° Canted Fins, 4° Canted Fins
Figure 7b - 60-mm Mortar Tube Mounted in a 105-mm Howitzer Recoil System
Figure 8 - Gun Mount Loaded on a 2-1/2 Ton Shop Truck
DRAG COEFFICIENT
VS
MEAN SQUARED YAW

FIG. 1
MOMENT COEFFICIENT

$K_M$ VS $\delta_b$

○ FIN - 0° CANT
X FIN - 2° CANT
△ FIN - 4° CANT

FIG. 2
LIFT COEFFICIENT

$\frac{K_{10}}{K_{20}} + K_{20}^2$

FIG. 3
ROLL RATE
vs
DISTANCE DOWN RANGE

FIN-CANT 4°

$\phi'(\text{DEG./FT.})$

DISTANCE DOWN RANGE (FT.)

FIG. 5
FIGURE 7a: Shell With Non-Canted Fins, 2° Canted Fins, 4° Canted Fins

FIGURE 7b: 60-mm Mortar Tube
Mounted in a 105-mm Howitzer Recoil System
APPENDIX C
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