AN IMPROVED PROJECTILE BOATTAIL. PART II.

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March 1976

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A series of projectile boattails have shown improved aerodynamic performance over the standard conical boattail. These boattails have equal or lower drag and an improved gyroscopic stability. Their Magnus and damping characteristics appear to be satisfactory so that the projectile should be dynamically stable. Also, these boattails increase the projectile wheel base considerably, thereby decreasing the balloting in the gun tube. The improved aerodynamic performance could lead to longer ranges, larger payloads, or lower spin rates for future projectiles.
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I. INTRODUCTION

The main purpose of a projectile boattail is to reduce drag, over that of a cylindrical boattailed projectile* (Figure 1), thereby increasing the range of the projectile. In past years various geometric shapes (a conical boattail has been the most popular) have been used to form the boattail and have depended on the reduced base area to reduce the drag. These boattails have worked well in reducing the drag; however, all of them develop a negative lift on the boattail which increases the unstable pitching moment and reduces the gyroscopic stability. These boattails (especially the conical boattail) also generate large Magnus forces and moments at transonic velocities which can adversely affect the dynamic stability of the projectile. Satisfactory gyroscopic and dynamic stability must be maintained so that the average angle of attack remains within low limits as the projectile moves along its trajectory. This permits accurate prediction of the projectile range.

Recently, the BRL has experimented with a series of boattail shapes, which do not have axial symmetry and which have a number of advantages over the axisymmetric boattails. These boattails are formed by cutting the main projectile cylinder with planes, inclined at a small angle to the main projectile axis, such that flat surfaces are created on the boattail. The flat surfaces increase the boattail lift so that the unstable pitching moment is decreased and the drag is reduced by the smaller base area. Also, these boattails have elements of the main cylinder extending to the base which increases the wheel base over that of the axisymmetric boattails. The increased wheel base will reduce gun tube balloting and possibly reduce muzzle jump and gun tube wear. Possible versions of these boattails are:

(1) A boattail formed using four cutting planes so that the base becomes an inscribed square (Figure 2).**

(2) A boattail formed using three cutting planes so that the base becomes an inscribed triangle (Figure 2).**

(3) Boattails formed similar to (1) or (2) but with the cutting plane widths limited so that added lifting surfaces are formed at the base corners (Figure 3).**

(4) Boattails formed similar to (1), (2), and (3) but with cutting planes canted so as to reduce the roll damping during flight (Figure 4).**

* Previously known as a square base configuration, but changed here to avoid confusion with the new version (1) boattail.

** Patent No. 3,873,048.
(5) A boattail formed by eliminating all of the main body cylinder volume not included inside the volume of two orthogonal wedges (Figure 5).* This version can be extended to zero base area or can be cut off at any station to form a cruciform base.

Characteristics of these new boattails which may be important are:

(1) The flat surfaces generated on the boattails may act as lifting surfaces, thereby increasing the lift on the aft portion of the projectile and decreasing the unstable pitching moment.

(2) All of these boattails have a more gradual reduction in cross sectional area than the conical boattails (Figure 6). This reduces the rapidity of flow expansion over the boattail and may be the reason for the reduction in Magnus forces observed at transonic speeds.

(3) The cylinder elements which extend to the base will form crude rotating fins which should have Magnus forces acting opposite to those on the body. The opposing forces should minimize the resultant Magnus force and moment about the projectile center of gravity.

Aerodynamic tests on these boattail configurations have been made to verify these characteristics and also to find the configuration having the best overall aerodynamic performance. These tests have been run in U.S. Government wind tunnels and ranges which were available to us for these purposes.

II. TEST FACILITIES

The wind tunnel facilities used for the tests so far are:

(1) The NASA Ames Research Center 12 ft. subsonic wind tunnel, \( M = 0.5, 0.7, \) and \( 0.9, 4\frac{1}{4}'' \) model, \( Re/ft = 1.35 \) to \( 2.8 \times 10^6 \) \( (Re/m = 4.23 \) to \( 9.2 \times 10^6) \).

(2) The Naval Ship Research and Development Center (NSRDC) 7 ft. x 10 ft. transonic wind tunnel, \( M = 0.5, 0.7, 0.9, 0.94, \) and \( 0.98, 4\frac{1}{4}'' \) model, \( Re/ft = 2.65 \) to \( 4.0 \times 10^6 \) \( (Re/m = 8.69 \) to \( 13.1 \times 10^6) \).

(3) The Ballistic Research Laboratories (BRL) 1 ft. supersonic wind tunnel, \( M = 1.75 \) to \( 4.0, 2\frac{1}{4}'' \) model, \( Re/ft = 3.6 \) to \( 7.0 \times 10^6 \) \( (Re/m = 11.8 \) to \( 23.0 \times 10^6) \).

* Patent disclosure has been submitted.

The range facility used for the tests is:

1. The Ballistic Research Laboratories (BRL) aerodynamic range, $M = 0.5$ to $4.0$, 20 mm models, atmospheric free flight Reynolds numbers.

III. WIND TUNNEL MODELS

These boattails are being tested using the Army-Navy Spinner Rocket nose and body with the complete configurations being 5, 6, or 7 calibers long.

Two sizes of models, $2\frac{1}{4}''$ (5.715 cm) and $4\frac{1}{4}''$ (10.795 cm) diameters, are required for the wind tunnel tests because of the variation of the tunnel sizes available for the different speed ranges. The models are designed according to the specifications described in reference 2. They consist of a central body mounted on ball bearings and a strain gage balance with various tails and noses attached to the central body. Variations in the lengths of the noses and tails make it possible to test body lengths of 5, 6, or 7 calibers. Tails for each boattail version, listed previously, are made using a $7^\circ$ cutting plane angle for both the $2\frac{1}{4}''$ and $4\frac{1}{4}''$ diameter models. Also, a straight cylindrical tail and a 1 caliber long $7^\circ$ conical boattail are available for comparison (Figure 1). Each boattail version can be tested on the $2\frac{1}{4}''$ diameter body with configuration lengths of 5, 6, or 7 calibers; however, the 5 caliber, $4\frac{1}{4}''$ model is limited to the straight cylinder, the conical boattail, and the square boattail. Six and seven caliber, $4\frac{1}{4}''$ diameter models of all of the boattail versions can be tested.

IV. RANGE MODELS

Five caliber long, 20 mm diameter, models of these configurations have been fired in the BRL Aerodynamic Range at transonic and supersonic velocities. These models are solid aluminum and have their centers of gravity approximately 60% of the length from the nose. All of the pitching and Magnus moment data have been transferred to the 60% location. The models were launched from two rifled barrels having twists of one revolution in 15.2 calibers and 1 revolution in 19 calibers.

V. RESULTS AND ANALYSIS

The results presented in this paper compliment, add to, and modify the results presented in reference 3 and present the main aerodynamic results presently available on the new boattails. The results are based on the experimental free flight range and wind tunnel data obtained on the 5 caliber long models. Some data have been obtained on the 6 and 7 caliber wind tunnel models, but these data are not sufficient to give a complete picture. The range flights yield the free flight drag, pitch data, Magnus, roll damping, and pitch damping moments at low angles of attack. The wind tunnel tests yield angle of attack drag*, detailed pitch data, Magnus force and moment over a range of spin and range of angle of attack (-10° to +15°). The data in the main report are presented mainly as faired curves for clarity; however, the detailed data are presented in the appendix of this report for the interested reader.

All of the supersonic wind tunnel data have been obtained using a boundary layer transition strip 1 caliber aft of the nose tip. The transonic tests did not use a trip, but depended on tunnel turbulence or high Reynolds number to trip the boundary layer. Shadowgraphs taken during all of the wind tunnel tests show the boundary layer to be turbulent at least from the base of the nose. The 20mm range models depended on firing conditions to trip the boundary layer so that all of the data presented here are for a turbulent boundary layer over the configuration. Previous tests on smooth wind tunnel bodies without a transition strip have shown that the boundary layer transition can move with spin. This, in some cases, results in nonlinear variations in the Magnus characteristics with spin.

The zero angle of attack drag coefficient, $C_{D_0}$, for the various boattails are compared in Figure 7. The triangular boattail has the lowest drag while the square boattail has a drag near the conical boattail. The cruciform boattail has the highest drag of all the configurations at supersonic speeds which is apparently due to low base pressures. The high drag rules out the use of the cruciform tail for long range projectiles; however, its low drag at high subsonic speeds and its relatively high stability, as explained later, at all Mach numbers may make it useful for other purposes.


* Some wind tunnel drag data are available, but breakage of drag balances due to model spin resonance with the drag link has caused severe problems in obtaining drag data with the model spinning.
The lower drag of the triangular boattail at supersonic speeds is probably due mainly to the smaller base area. However, recent supersonic wind tunnel tests have shown that the triangular boattail has a higher base pressure than the conical boattail, thereby indicating lower viscous losses in the boattail flow.

The geometric asymmetry of the triangular boattail may also decrease the drag at low angles of attack. At zero spin the asymmetry produces an asymmetric drag polar (Figure 8), so that drag values at constant angle of attack with spin will be the average drag between plus and minus angles of attack. It appears that this will decrease $C_\text{D}_\alpha^2$ at least at low angles of attack; however, this thought has not been thoroughly investigated due to strain gage balance difficulties.

The first transonic wind tunnel tests at Ames and NSRDC and a few free flight tests at transonic velocities showed that the drag of the added lifting surface version (Figure 3) is considerably higher than that of versions 1 or 2 (Figure 2). This plus the minimal increase in stability have curtailed further testing of version 3 to a later date.

The wind tunnel tests have shown some variation of drag with spin on the new boattails (Figure 9). The straight boattails have minimum drag at zero spin while the twisted boattails have minimum drag at the twist rate. Again, the available data to confirm these results are limited due to mechanical failure of the drag balance.

The gyroscopic stability of a projectile is directly proportional to the spin squared and inversely proportional to the aerodynamic pitching moment.* Since stable flight of a projectile requires that the gyroscopic stability remain above 1, it behooves the designer to select a projectile shape having the best pitching moment. Conical boattails reduce the normal force (Figure 10) and increase the unstable pitching moment, especially at transonic velocities (Figure 11). However, as seen in Figures 10, 11, and 12, the new boattails not only reduce the unstable pitching moments at all Mach numbers below that of the conical boattail, but at all supersonic Mach numbers of interest reduce the pitching moment over that of the cylindrical tail. For the first time in artillery projectile design we can employ a boattail which not only decreases drag, but also increases the stability of the projectile. This could aid projectile design, for, in most instances, the projectile design is governed by the maximum unstable pitching moment attained at any Mach number within the projectile flight envelope.

* All presented pitching moments are about a C.G. located 60% of the body length aft of the nose.
Some interest has been shown in comparing these boattails to a conical boattail with fins or strakes. However, a direct comparison is impossible with previous data since the finned boattails have been tried on other projectile shapes. To obtain a direct comparison a 1 caliber long, 7° conical boattail with 4 in-caliber fins was tested on the 2½" wind tunnel model at supersonic speeds. The results (Figures 10 and 11) show that the finned conical boattail has about the same normal force and pitching moment as the square boattails. The finned boattail drag will be greater than the bare conical boattail due to the additional fin drag.

One of the aerodynamic problems of the new boattails is the high roll damping inherent in the straight configurations. Roll damping moment coefficients up to -.1 were measured during the range flights and this is sufficient to despin a typical projectile to instability during flight. To circumvent this, it is necessary to twist or cant the boattails so that spin will be maintained during the flight. Range firings of these boattails with 0 and 1/15 (rev/cal) twists yield the following rolling moments.

<table>
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<tr>
<th>Boattail Type</th>
<th>$C_{\delta p}$</th>
<th>$C_{\delta \delta}$</th>
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<tr>
<td>Square Boattail</td>
<td>-.055</td>
<td>+.037</td>
</tr>
<tr>
<td>Triangular Boattail</td>
<td>-.098</td>
<td>+.084</td>
</tr>
<tr>
<td>Cruciform Boattail</td>
<td>-.073</td>
<td>+.063</td>
</tr>
<tr>
<td>Conical or Cylindrical Boattail</td>
<td>-.015</td>
<td>0</td>
</tr>
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Even though it is not possible to theoretically predict the Magnus force on a projectile, it is possible by studying shadowgraphs and analyzing the force and moment test results to visualize the mechanisms producing the Magnus force. The picture which is visualized is that of an aerodynamic body composed of the actual projectile body surrounded by a warpable, viscous, aerodynamic body made up of the boundary layer.

At all Mach numbers the Magnus force is generated to a large extent by the shape of the boundary layer, and the shape in turn is influenced greatly by the viscous twist or warpage due to the projectile spin (reference 4). At zero angle of attack the warpage of the boundary layer due to spin is axisymmetric about the main centerline, so that the resulting aerodynamic forces and moments are zero except for drag and rolling moment. At small angles of attack, the boundary layer thickens on the lee side of the body, but at zero spin the boundary layer maintains mirror symmetry. A normal force and pitching moment are generated, but the side forces and moments remain zero. With spin
the thickened portion of the boundary layer twists in the direction of spin, all symmetry is destroyed, and a side force and moment are generated.

If a conical boattail is used in place of the cylindrical tail, at subsonic or transonic velocities, the boundary layer thickens due to the flow expansion over the boattail. The thicker boundary layer is distorted more by spin and a larger Magnus force is created (Figure 13 and reference 5). At supersonic speeds the Prandtl-Meyer expansion over the conical boattail holds the boundary layer to thinner values so that large increases in Magnus force do not occur. The large increase in Magnus force and moment caused by the conical boattail at transonic velocities may be sufficient to destabilize an already marginally (gyroscopic) stable projectile (reference 6) by causing large changes in dynamic stability.

Wind tunnel and range tests on the new boattails indicate that no large Magnus forces and moments are generated at any of the tested Mach numbers (Figure 13). The wind tunnel tests at M > 1 show the Magnus forces and moments to be linear over the spin range tested (Figure 14) and approximately linear over an angle of attack range of at least ±3° (Figure 15)*. When nonlinearities do occur they appear to be in the direction of decreasing Magnus force and moment.


* Additional subsonic and transonic wind tunnel tests must be run to verify this at the lower speed ranges. The subsonic and transonic wind tunnel tests run to date have given sketchy Magnus results due to the high sensitivity of Magnus characteristics to tunnel turbulence and flow inclination.
The side force generated on the twisted boattails modifies the above boundary layer picture appreciably and results in smaller Magnus forces.* At small angles of attack and zero spin the boundary layer is distorted by the twist in the opposite direction from the intended spin. For a right hand twist the thick or lee side of the boundary layer twists to the left and creates a side force to the right. When the body spins in the direction intended or caused by the twist a Magnus force is generated to the left (Figure 14). This was also noticed by M. Sylvester in reference 7. As the spin increases, the combined side force changes sign so that at typical projectile spin rates the side force is less than on a straight boattail configuration. From Figure 14 it can be seen that for a given $\alpha$ the side force and moment for a twisted boattail can be expressed as:

$$C_Y = C_{Y_0} + C_{N_p} \frac{p_d}{V}$$

$$C_n = C_{n_0} + C_{m_p} \frac{p_d}{V}$$

where $C_{Y_0}$ and $C_{n_0}$ are the zero spin offsets at each angle of attack and $C_{N_p}$ and $C_{m_p}$ are the Magnus slopes at each angle of attack. These have been determined from wind tunnel tests (Figure 16) at supersonic speeds. It can also be seen that $C_{N_p}$ and $C_{m_p}$ are spin dependent (Figure 17) for the twisted configurations and must be evaluated for


* Figure 16 of reference 3 is in error. At the time these data were taken, the offsets, $a$ and $b$, mentioned in this paragraph were not measured.
all spin rates (pd/V) encountered during flight. References 8 and 9 present Magnus data on finned boattail configurations. Even though these data show fins reduce the Magnus properties, they do not indicate the zero spin offset shown by the BRL data.

Aerodynamic pitch damping measurements have been limited to range data and indicate that the aerodynamic damping is independent of the configuration (Figure 18). This is surprising for the lifting surfaces on the new boattails should increase the pitch damping. No pitch damping data are available on a corresponding finned boattail configuration; however, unpublished data on the Navy 5 inch/54 projectile with and without boattail fins show the same degree of damping. Possibly the longer 6 or 7 caliber configurations will show a difference in the damping coefficient when they are tested.

VI. CONCLUSIONS

The aerodynamic data obtained show that all of the new boattails change the aerodynamic characteristics of a projectile considerably.

(1) The new boattails improve the pitching moment of projectiles over that of the conical boattail.

(2) The square boattail has about the same drag reduction as the conical boattail.

(3) The cruciform boattail drag is too high and eliminates it as a viable configuration.

(4) The twisted triangular boattail has the best aerodynamic properties for projectiles. It has the lowest drag, good pitching moments, and low Magnus moments for good stability.


REFERENCES


Figure 1. The Cylindrical and Conical Boattail, Dimensions in Calibers, $\varepsilon = 5$, 6, or 7 calibers
Figure 2. The Square and Triangular Boattail, Dimensions in Calibers, \( \varepsilon = 5, 6, \) or 7 calibers
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Figure 17. The Magnus Characteristics of the Triangular Boattail With a 1/20 Twist at a Spin Rate \((pd/V = .412)\), \(M = 2.5\), \(R_{\text{dia}} = 950,000\)
Figure 18. The Damping in Pitch of Various Boattails
### APPENDIX A

Aerodynamic Data on the Improved Projectile Boattails

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<td>7° Cruciform Boattail Straight</td>
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<td>7° Cruciform Boattail Canted</td>
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### FREE FLIGHT RANGE DATA

**5 cal. A-N Spinner Rocket with 7° Straight Square Boattail**

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<th>M</th>
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<th>C_mα</th>
<th>C_NPa</th>
<th>C_mPa</th>
<th>C_Lp</th>
<th>C_Dδ</th>
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<td>2.85</td>
<td>1.28</td>
<td>.277</td>
<td>3.53</td>
<td>3.13</td>
<td>-.55</td>
<td>+.36</td>
<td>-8.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

C_Dα² = 6

---

**5 cal. A-N Spinner Rocket with 7° Twisted Square Boattail**

<table>
<thead>
<tr>
<th>M</th>
<th>R dia x 10^-6</th>
<th>C_D0</th>
<th>C_Nα</th>
<th>C_mα</th>
<th>C_NPa</th>
<th>C_mPa</th>
<th>C_Lp</th>
<th>C_Dδ</th>
<th>C_mq + C_mα</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.02</td>
<td>.46</td>
<td>.395</td>
<td>4.26</td>
<td>-.17</td>
<td>-.055</td>
<td>+.037</td>
<td>-10.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.03</td>
<td>.46</td>
<td>.412</td>
<td>4.05</td>
<td>+1.07</td>
<td>-10.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.52</td>
<td>.54</td>
<td>.418</td>
<td>2.17</td>
<td>4.05</td>
<td>+1.07</td>
<td>-10.8</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1.54</td>
<td>.422</td>
<td>2.40</td>
<td>3.99</td>
<td>+1.4</td>
<td>-10.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.88</td>
<td>.343</td>
<td>3.09</td>
<td>3.49</td>
<td>+1.4</td>
<td>-10.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.88</td>
<td>.341</td>
<td>3.19</td>
<td>3.54</td>
<td>+1.4</td>
<td>-10.6</td>
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<td></td>
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<tr>
<td>2.88</td>
<td>1.32</td>
<td>.275</td>
<td>3.13</td>
<td>3.14</td>
<td>+1.4</td>
<td>-10.6</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>3.10</td>
<td>1.38</td>
<td>.266</td>
<td>3.20</td>
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<td>+1.4</td>
<td>-10.6</td>
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</tr>
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<td>3.12</td>
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<td>.247</td>
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<td>+1.4</td>
<td>-10.6</td>
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</tr>
</tbody>
</table>

C_Dα² = 6
### FREE FLIGHT RANGE DATA (continued)

#### 5 cal. A-N Spinner Rocket with 7° Straight Triangular Boattail

<table>
<thead>
<tr>
<th>M Mid-Range Value</th>
<th>R\text{\textit{dia}} \times 10^{-6}</th>
<th>C_D</th>
<th>C_{N\alpha}</th>
<th>C_{m\alpha}</th>
<th>C_{N_{p\alpha}}</th>
<th>C_{m_{p\alpha}}</th>
<th>C_{\ell_{\delta}}</th>
<th>C_{m_q} + C_{m_{\alpha}}</th>
</tr>
</thead>
<tbody>
<tr>
<td>.93</td>
<td>.42</td>
<td>.227</td>
<td>2.28</td>
<td>3.79</td>
<td>+.01</td>
<td>-.19</td>
<td>-.098</td>
<td>0</td>
</tr>
<tr>
<td>.94</td>
<td>.42</td>
<td>.192</td>
<td>2.53</td>
<td>3.80</td>
<td>+.57</td>
<td>+.09</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>.96</td>
<td>.43</td>
<td>.208</td>
<td>2.56</td>
<td>4.11</td>
<td>-.18</td>
<td>+.17</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>1.04</td>
<td>.46</td>
<td>.398</td>
<td>2.75</td>
<td>3.74</td>
<td>-.11</td>
<td>+.09</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>1.16</td>
<td>.52</td>
<td>.411</td>
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<td>3.50</td>
<td>-.24</td>
<td>-.07</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>1.49</td>
<td>.67</td>
<td>.380</td>
<td>3.30</td>
<td>3.48</td>
<td>-1.40</td>
<td>-.08</td>
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<tr>
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<td>.76</td>
<td>.357</td>
<td>3.00</td>
<td>3.33</td>
<td>-.68</td>
<td>-.08</td>
<td>-</td>
<td>0</td>
</tr>
</tbody>
</table>

#### 5 cal. A-N Spinner Rocket with 7° Twisted Triangular Boattail

<table>
<thead>
<tr>
<th>M Mid-Range Value</th>
<th>R\text{\textit{dia}} \times 10^{-6}</th>
<th>C_D</th>
<th>C_{N\alpha}</th>
<th>C_{m\alpha}</th>
<th>C_{N_{p\alpha}}</th>
<th>C_{m_{p\alpha}}</th>
<th>C_{\ell_{\delta}}</th>
<th>C_{m_q} + C_{m_{\alpha}}</th>
</tr>
</thead>
<tbody>
<tr>
<td>.973</td>
<td>.44</td>
<td>.251</td>
<td>1.91</td>
<td>4.28</td>
<td>-1.35</td>
<td>-1.12</td>
<td>-.098</td>
<td>+.084</td>
</tr>
<tr>
<td>.973</td>
<td>.44</td>
<td>.239</td>
<td>2.05</td>
<td>4.28</td>
<td>-.67</td>
<td>-.78</td>
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<td>0</td>
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<tr>
<td>.984</td>
<td>.45</td>
<td>.302</td>
<td>2.10</td>
<td>4.35</td>
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<td>-.14</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>1.00</td>
<td>.45</td>
<td>.331</td>
<td>3.10</td>
<td>4.29</td>
<td>1.30</td>
<td>+.15</td>
<td>-</td>
<td>0</td>
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<tr>
<td>1.127</td>
<td>.51</td>
<td>.397</td>
<td>2.36</td>
<td>4.02</td>
<td>-.92</td>
<td>-.43</td>
<td>-</td>
<td>0</td>
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<tr>
<td>1.96</td>
<td>.89</td>
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<td>3.31</td>
<td>-.41</td>
<td>-.27</td>
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<tr>
<td>1.97</td>
<td>.89</td>
<td>.320</td>
<td>3.34</td>
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<td>-.16</td>
<td>-</td>
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</tr>
<tr>
<td>2.47</td>
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<td>.280</td>
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<td>-.09</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>3.15</td>
<td>1.41</td>
<td>.256</td>
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<td>2.95</td>
<td>-.12</td>
<td>-.03</td>
<td>-</td>
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</tr>
</tbody>
</table>
FREE FLIGHT RANGE DATA (continued)

5 cal. A-N Spinner Rocket with 7° Straight Cruciform Boattail

<table>
<thead>
<tr>
<th>M</th>
<th>( R_{\text{dia}} \times 10^{-6} )</th>
<th>( C_D )</th>
<th>( C_{N_\alpha} )</th>
<th>( C_{m_\alpha} )</th>
<th>( C_{N_p} )</th>
<th>( C_{m_p} )</th>
<th>( C_\ell )</th>
<th>( C_{L_5} )</th>
<th>( C_{m_q} + C_{m_\alpha} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.44</td>
<td>1.65</td>
<td>.458</td>
<td>2.23</td>
<td>2.40</td>
<td>-.75</td>
<td>.44</td>
<td>.073</td>
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<td>-17.1</td>
</tr>
<tr>
<td>1.59</td>
<td>1.71</td>
<td>.441</td>
<td>3.32</td>
<td>3.11</td>
<td>-.34</td>
<td>.26</td>
<td>.68</td>
<td>0</td>
<td>-14.3</td>
</tr>
<tr>
<td>2.42</td>
<td>1.342</td>
<td>3.44</td>
<td>2.74</td>
<td>-1.12</td>
<td>.29</td>
<td>.68</td>
<td>0</td>
<td>0</td>
<td>-7.5</td>
</tr>
</tbody>
</table>

5 cal. A-N Spinner Rocket with 7° Twisted Cruciform Boattail

<table>
<thead>
<tr>
<th>M</th>
<th>( R_{\text{dia}} \times 10^{-6} )</th>
<th>( C_D )</th>
<th>( C_{N_\alpha} )</th>
<th>( C_{m_\alpha} )</th>
<th>( C_{N_p} )</th>
<th>( C_{m_p} )</th>
<th>( C_\ell )</th>
<th>( C_{L_5} )</th>
<th>( C_{m_q} + C_{m_\alpha} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>.965</td>
<td>.44</td>
<td>.265</td>
<td>2.60</td>
<td>3.68</td>
<td>-.59</td>
<td>-.29</td>
<td>.073</td>
<td>+.063</td>
<td>-9.7</td>
</tr>
<tr>
<td>1.138</td>
<td>.51</td>
<td>.487</td>
<td>3.02</td>
<td>3.24</td>
<td>-.03</td>
<td>-.37</td>
<td>.68</td>
<td>0</td>
<td>-9.7</td>
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<tr>
<td>1.941</td>
<td>.387</td>
<td>3.50</td>
<td>2.98</td>
<td>-.88</td>
<td>-.10</td>
<td>.68</td>
<td>0</td>
<td>0</td>
<td>-9.6</td>
</tr>
<tr>
<td>3.103</td>
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<td>.281</td>
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<td>+.33</td>
<td>-.06</td>
<td>.68</td>
<td>0</td>
<td>0</td>
<td>-11.4</td>
</tr>
</tbody>
</table>

All flights are low angle of attack, Maximum \( \alpha = 5^\circ \).
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ZERO BOATTAIL
MACH 0.50
R(DIA) 0.99 X 10^6

CONFIG 5.00 RUN 55.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, CAL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET. ZERO BOATTAIL
MACH 0.70
R(DIA) 0.57 X 10^6
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, ZERO BOATTAIL
MACH 1.75
R(DIA) 0.91 X 10^6

PITCH MOUNT COEF.
X NORMAL FORCE COEF.

CONFIG = 5.00 RUN = 7.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, ZERO BOATTAIL
MACH 1.75  PD/V 0.37  R(DIA) 0.91 \times 10^6

\[ \text{MCP, CMP, MAGNUS MOMENT COEF.} \]

\[ \text{MCP, FROM NOSE} \]

\[ \text{ANGLE OF ATTACK, DEG.} \]

\[ \text{CONFIG = 5.00 RUN = 7.} \]
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, ZERO BOATTAIL
MACH 2.50
R/DIA: 0.94 X 10^6

CONFIG 5.00 RUN 8

PITCH MOMENT COEF.

NORMAL FORCE COEF.

CAL. FROM NOSE

-12 -9 -6 -3 0 3 6 9 12 15 18

ANGLE OF ATTACK, DEG.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, ZERO BOATTAIL
MACH 2.50  PD/V 0.31  R(DIA) 0.94 X 10^6

CONFIG 5.00  RUN  8
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, ZERO BOATTAIL
MACH 4.00
R(DIA) 1.00 X 10^6

---

CONFIG 5.00 RUN 9

47
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, ZERO BOATTAiL
MACH 4.00  PD/V 0.26  R(DIA) 1.00 X 10^6

CONFIG = 5.00  RUN = 9.

48
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH 0.50
R(DIA) 0.55 x 10^6

CONFlG= 5.10 RUN= 1.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH 0.50
R(ODIA) 0.88 x 10^6

**Diagram:**
- **Cn** vs **CM**: Pitch moment coefficient
- **CM** vs **Cn**: Normal force coefficient
- **MCP**: Ch. from nosl
- **CAL. FROM NOSE**: -12 to 18
- **ANGLE OF ATTACK, DEG.**: -12 to 18

**Legend:**
- ⬤ Pitch moment coeff.
- × Normal force coeff.

**Configuration:** Config 5.10 Run 3.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH 0.50
R(DIA) 1.00 X 10^6

-12 -9 -6 0 3 6 9 12 15 18
ANGLE OF ATTACK, DEG.

-2 0 2 4
MCP FROM NOSE

-0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8
PITCH MOMENT COEF.

-1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8
NORMAL FORCE COEF.

□ PITCH MOMENT COEF.
× NORMAL FORCE COEF.

CONFIG = 5.10  RUN = 58.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH .50
RADIUS .17 X 10^4

PITCH MOMENT COEF.
× NORMAL FORCE COEF.

1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0

MCP
CAL. FROM NOSE

12 15 18
0 3 6 9 12

ANGLE OF ATTACK, DEG.

CONFIG 5.10 RUN 5.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, ESL
AMES 18 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET. ONE CAL. 7 DEG. BOATTAIL
MACH 0.70
R(DIA) 0.55 X 10^6
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET. ONE CAL. 7 DEG. BOATTAIL
MACH 0.70
R(DIA) 0.57 X 10^6

PITCH MOMENT COEF. AND NORMAL FORCE COEF.

CONFIG = 5.10 RUN = 57.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKETS, ONE CAL. 7 DEG. BOATTAIL
MACH 0.70
R(DIA) 0.86 X 10^5

PITCH MOMENT COEF. AND NORMAL FORCE COEF.

PITCH MOMENT COEF.
× NORMAL FORCE COEF.

CAL. FROM NOSE

-12 -9 -6 -3 0 3 6 9 12 15 18

ANGLE OF ATTACK, DEG.

CONFIGN= 5.10 RUN= 4.

55
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKETS, ONE CAL. 7 DEG. BOATTAIL
MACH 0.50    PD/V 0.67    R(DIA) 0.48 X 10^6

CONFIG= 5.10   RUN=  6.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKETS, ONE CAL. 7 DEG. BOATTAIL
MACH 0.80     PD/V 0.42     R(DIA) 0.60 x 10^6

CONFIG 5.10  RUN=  2.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, ESL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-W SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH 0.90
R(DIA) 0.48 X 10^6

CONFIG = 5.10 RUN = 56.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
3 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH 0.90

PITCH MOMENT COEF. AND NORMAL FORCE COEF.

PITCH MOMENT COEF.
X NORMAL FORCE COEF.

ANGLE OF ATTACK, DEG.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH 0.94  PD/V 0.37  R(IA) C.71 X 10^6

CONFIG  5.10  RUN= 8.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH 1.15
R(DIA) .67 X 10^6

PITCH MOMENT COEF. AND NORMAL FORCE COEF.

PITCH MOMENT COEF.
NORMAL FORCE COEF.

ANGLE OF ATTACK, DEG.

CONFIG 5-10 RUN 3.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NASA DC 7X10 FT. TRANSONIC WIND TUNNEL.
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH 1.15  PD/V 0.31  R(ODIA) 0.66 X 10^6

CONFIG 5.10  RUN 4  64
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-W SPINNER ROCKET. ONE CAL. 7 DEG. BORTTAIL
MACH 1.75
R(DIA) 0.92 X 10^6

PITCH MOMENT COEF. AND NORMAL FORCE COEF.

X PITCH MOMENT COEF.
X NORMAL FORCE COEF.

CAL. FROM NOSE

-2 -1 0 1 2

ANGLE OF ATTACK, DEG.

-12 -6 0 3 6 9 12 15 18

CONFIG 5.10 RUN 1.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET. ONE CAL. 7 DEG. BOATTAIL
MACH 1.75      PD/V 0.37      R(DIA) 0.92 X 10^6

+ CONFIG = 5-10  RUN = 1.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNEL BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, CNC CAL. 7 deg. BOATTAIL
MACH 2.50
R(DEL) 0.94 X 10^6

PITCH MOMENT COEFF. AND NORMAL FORCE COEFF.

PITCH MOMENT COEFF.
NORMAL FORCE COEFF.

NCP
CAL. FROM NOSE

ANOE OF ATTACK, DEG.

CONIFG: 5.10 RUN: 2
67
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH 2.50        PD/V 0.31        R(DIA) 0.94 X 10^6

CONFIG= 5.10 RUN= 2.

68
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, ESL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG BOTTAIL
MACH 4.00  
R(DIA) 0.64 X 10^6

PITCH MOMENT COEF. AND NORMAL FORCE COEF.

NCP  CAL. FROM NOSE

-12  -9  -6  -3  0  3  6  9  12  15  18

ANGLE OF ATTACK, DEG.

CONFIG 5-10 RUN 9.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH 4.00  PD/V 0.26  R(DIA) 0.64 x 10^6

CONFIG 5.10  RUN  3

70
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT MACH 0.50 ROLL ZERO DEG. R(DIA) 1.00 x 10^6

-12 -9 -6 -3 0 3 6 9 12 15 18
ANGLE OF ATTACK, DEG.

CONFIG 5.20 RUN 49.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET. SQUARE BOATTAIL, STRAIGHT MACH 0.50 ROLL 45 DEG. R(DIA) 1.00 x 10^6

Diagram showing data points for pitch moment coefficient and normal force coefficient as a function of angle of attack. Legend indicates squares for pitch moment coefficient and crosses for normal force coefficient.

CONFIG= 5.20 RUN= 52.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL.
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.50       R(DIR) 0.99 X 10^6

-12 -9 -6 -3 0 3 6 9 12 15 18
ANGLE OF ATTACK, DEG.

CONFIG = 5.20 RUN = 5.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, ESL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL.
5 CAL. A-W SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.50
PD/V 0.32          R(DIA) 0.94 X 10^6

ANGLE OF ATTACK, DEG.
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20

CAL. FROM NOSE
6
4
2
0
-12 -9 -6 -3 0 3 6 9 12 15 18

CMF
MAGNUS FORCE COEF.
MAGNUS MOMENT COEF.
CNP

CONFIG 5.20 RUN 6.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WING TUNNELS BRANCH, EBL
NSRDC 7X10 FI: TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.60
PD/V 0.64
R(DIA) 0.94 x 10^6

ANGLE OF ATTACK, DEG.

CAL. FROM NOSE

-12 -9 -6 -3 0 3 6 9 12 15 18

MCP

CMP

CNP

1 CONFIG 5.20 RUN 6.

75
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.70 ROLL ZERO DEG. RADIUS 0.57 X 10^6

\[ C_n \]
\[ C_m \]
PITCH MOMENT COEF., AND NORMAL FORCE COEF.

\[ NCP \]
CAL. FROM NOSE

\[ \text{ANGLE OF ATTACK, DEG.} \]

\[ \text{CONFIG = 5.20 RUN = 48.} \]
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.70      ROLL 45 DEG.      R(DIA) 0.56 x 10^6

CONFIG= 5.20  RUN=  51.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. 2-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.70
R(DIA) 1.22 X 10^6

PITCH MOMENT COEF.
\( \times \) NORMAL FORCE COEF.

\( 0 \) \( 3 \) \( 6 \) \( 9 \) \( 12 \) \( 15 \) \( 18 \)

CONFIG: 5.20 RUN: 8.
78
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.70       PD/V 0.24       R(DIA) 1.27 x 10^6

CONFIG= 5.20        RUN= 7.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.70    PD/V 0.40    R(DIA) 1.27 X 10^6

CONFIG 5.20   RUN 7.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.90 ROLL ZERO DEG. R(DIA) 0.50 X 10^6

PITCH MOMENT COEF. AND NORMAL FORCE COEF.

PITCH MOMENT COEF.
× NORMAL FORCE COEF.

NCP
CAL. FROM NOSE

ANGLE OF ATTACK, DEG.

CONFIG = 5.20 RUN = 47.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT MACH 0.90 ROLL 45 DEG. R(DIA) 0.48 X 10^-6

! CONFIG = 5.20 RUN = 50.

+
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSROC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.90
R(DIA) 1.42 X 10^6

-2 -1 0 1 2 3 4
\text{CAL. FROM NOSE}

-12 -9 -6 -3 0 3 6 9 12 15 18
\text{ANGLE OF ATTACK, DEG.}

\text{PITCH MOMENT COEF.}
\text{NORMAL FORCE COEF.}

\text{CONFG} 5.20 \text{ RUN} 9.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.90     PD/V 0.19      R(DIA) 1.39 X 10^6

ANGLE OF ATTACK, DEG.

MCP CAL. FROM NOSE
0  2  4  6

MAGNUS MOMENT COEF. AND MAGNUS FORCE COEF.
-0.20 -0.15 -0.10 -0.05 0.00 0.05 0.10 0.15 0.20

CMP

CD

WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.90     PD/V 0.19      R(DIA) 1.39 X 10^6

CONFIG 5.20 RUN 10.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.90  PD/V 0.38  R(DIA) 1.39 X 10^6

CONFIG: 5.20  RUN: 10.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
N53626 7X10 FT. TRANSONIC WIND TUNNEL.
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.94
DIAM 1.48 X 106

PITCH MOMENT COEF. AND NORMAL FORCE COEF.

NCP FROM NOSE

ANGLE OF ATTACK, DEG.

CONFIG 5.20 RUN 11.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. 4-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.94 PD/V 0.18 R(DIA) 1.41 X 10^6

ANGLE OF TRACK, DEG.

MCP CAL. FROM NOSE

-12 -9 -6 -3 0 3 6 9 12 15 18

CONFIG 5.20 RUN 12
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.94  PD/V 0.36  R(DIA) 1.41 X 10^6

\[ CONFIG = 5.20  \quad RUN = 12 \]
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 BT-FTRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.98          PD/V 0.17          R(DIA) 1.42 X 10^6

CONFIG= 6.20  RUN= 10
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKETS. SQUARE BOATTAIL. STRAIGHT
MACH 0.98 PD/V 0.35 R(DIA) 1.42 X 10^6

CONFIG: 5.20 RUN: 13.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT MACH 1.76
RADIUS 8.92 X 10^6

\[ \text{Pitch Moment Coef. and Normal Force Coef.} \]

\[ \text{NCP from Nose} \]

\[ \text{Angle of Attack, Deg.} \]

\text{CONFIG = 5.20 RUN = 10.}

92
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 1.75     PD/V 0.31     R(DIA) 0.92 X 10^-6

MAGNUS MOMENT COEF. AND MAGNUS FORCE COEF.

MCP

CAL. FROM NOSE

ANGLE OF ATTACK, DEG.

†CONFIG 5.20 RUN 10.  93
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WING TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 2.50   PD/V 0.28   R(DIA) 0.94 X 10^6

CONFIG = 0.20   RUN = 11.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EGL
5 CAL. A-N-SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 4.00

PITCH MOMENT COEF. AND NORMAL FORCE COEF.

-0.8
-0.6
-0.4
-0.2
0
-0.2
-0.4
-0.6
-0.8

NCP
CAL. FROM NO SL

-10 -6 -3 0 3 6 9 12 15 18

ANGLE OF ATTACK, DEG.

CONFIG: 5.20 RUN: 12
U.S. ARMY BALLISTIC RESEARCH LABORATORY
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 4.00  PD/V 0.24  R(DIA) 0.65 X 10^6

CONFIG 5.20  RUN 12.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, ESL
NSRDC 7X10 Ft., TRANSONIC WIND TUNNEL:
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, CANTED
MACH 0.50    PD/V 0.30    RADIUS 1.01 X 10^6

ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.

CONFIG 5.30 RUN 17.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7x10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET. SQUARE BOATTAIL. CANTLD
MACH 0.50 PD/V 0.66 R(DIA) 1.01 X 10^6

ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.

CONFIG: 5.30 RUN: 17.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL.

5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, CANTED
MACH 0.90
PD/V 0.19
R(DIA) 1.39 X 10^6

![Graph showing data points for ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.]

CONFIG = 5.30 RUN = 19.
ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.

CONFIG = 5.30    RUN = 19.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, CBL
NSRDC 7X10 FT TRANSONIC WIND TUNNEL
5 CAL. R-N SPINNER ROCKET, SQUARE BOATTAIL, CANTED
MACH 0.94
R(DIA) 1.43 X 10^6

PITCH MOMENT COEF. AND NORMAL FORCE COEF.

CM

-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1.0
1.2

MCP
CAL. FROM NOSE

-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

ANGLE OF ATTACK, DEG.

ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.

CONFIG= 5-30 RUN= 16.

103
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, CANTED
MACH 0.94    FD/V 0.18   R(DIA) 1.42 x 10^6

ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.

CONFIG = 5.30  RUN = 15.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSSONIC WIND TUNNEL
5 CAL. R-N SPINNER ROCKET, SQUARE BOATTAIL, CANTED
MACH 0.94       PD/V 0.36       R(CIA) 1.42 x 10^6

ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.

†CONFIG = 5.36  RUN = 15.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, ESL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, CANTED
MACH 1.75
R(DIA) 0.90 X 10^{-6}

\[ \text{CONFIG = 5.30 RUN = 25} \]
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, FBL
5 CAL. A-N SPINNER ROCKET. SQUARE BOATTAAIL, CANTED
MACH 1.75  PO/V 0.37  R/DIA) 0.40 x 10^6

THESE DATA MUST BE COMBINED WITH ZERO SPIN SIDE FORCE AND
YAWING MOMENT ON NEXT PAGE TO OBTAIN CM AND CP.

CONFIG 5.30  RUN 25.
SIDE FORCE AND YAWING MOMENT AT ZERO SPIN

5 cal. A-N with Canted Square Boattail
Mach 1.75 \( R_d 0.9 \times 10^6 \)

![Graph showing side force and yawing moment vs. angle of attack.](image-url)
U.S. Army Ballistic Research Laboratories
Wind Tunnels Branch, EBL
5 Cal. A-N Spinner Rocket, Square Boattail, Canted
Mach 2.50
R(DIA) 0.94 x 10^6

PITCH MOMENT COEF. AND NORMAL FORCE COEF.

-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2

CM

PITCH MOMENT COEF.
X NORMAL FORCE COEF.

NC

CAL. FROM NOSE

-12 -9 -6 -3 0 3 6 9 12 15 18

ANGLE OF ATTACK, DEG.

CONFIG = 5.30 RUN = 26.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, CANTED
MACH 2.50    PD/V 0.31    R(DIA) 0.94 X 10^6

CONFIG 5.30 RUN 26.
SIDE FORCE AND YAWING MOMENT AT ZERO SPIN

5 cal. A-N with Canted Square Boattail
Mach 2.5 $R_d 0.94 \times 10^6$

$C_y$

$C_n$

ANGLE OF ATTACK ~ DEG.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-K SPINNER ROCKET, SQUARE BOATTAIL, CANTED
MACH 4.00 R(DIA) 0.99 X 10^-6

PITCH MOMENT COEFF. AND NORMAL FORCE COEFF.

MCP FROM NSEL

12 -9 -6 -3 0 3 6 9 12 15 18
ANGLE OF ATTACK, DEG.

FIG= 5.30 RUN= 27.
THESE DATA MUST BE COMBINED WITH ZERO SPIN SIDE FORCE AND YAWING MOMENT ON NEXT PAGE TO OBTAIN $C_{MPa}$ AND $C_{MPa}$. 

**Config**: 5.30  **Run**: 27.
SIDE FORCE AND YAWING MOMENT AT ZERO SPIN

5 cal. A-N with Canted Square Boattail
Mach 4.0  R_d 0.99 X 10^6

![Graph showing Side Force (C_y) and Yawing Moment (C_n) vs. Angle of Attack (°)]
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WING TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL W/FINS, STRAIGHT
MACH 0.50 ROLL ZERO DEG. R(DIA) 1.00 X 10^6

[Graph showing normal force coefficient and pitch moment coefficient vs. angle of attack]

- CONFIG 5.40 RUN 43.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNEL BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOAT-TAIL-W-FINS-STRAIGHT
MACH 0.50
RE PER FT. 2.634 X 10^6

- PITCH MOMENT COEF.
- NORMAL FORCE COEF.

CONFIG 5.40 RUN 43
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL W/FINS, STRAIGHT
MACH 0.50 ROLL 45 DEG. R(DIA) 1.00 X 10^-6

CONFIG: 5.40 RUN: 46.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 ft. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL A/FINS, STRAIGHT MACH 0.50
RADIUS: 1.05 x 10^6

CONIFG = 540  RUN = 36
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL W/FINS, STRAIGHT
MACH 0.70 ROLL ZERO DEG. R(DIA) 0.57 X 10^6

PITCH MOMENT COEF. AND NORMAL FORCE COEF.

PITCH MOMENT COEF.
X NORMAL FORCE COEF.

CONFIG = 5.40 RUN = 42.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET. SQUARE BOATTAIL W/FINS: STRAIGHT
MACH 0.70 ROLL 45 DEG. R(DIA) 0.57 X 10^6

PITCH MOMENT COEF.
NORMAL FORCE COEF.

CONFIG = 5.40 RUN = 45.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER-ROCKET, SQUARE BOATTAIL W/FINS, STRAIGHT
MACH 0.90       ROLL ZERO DEG.       R(DIA) 0.49 X 10^6

\[ \begin{align*}
CN & \quad PITCH MOMENT COEF. \\
CM & \quad NORMAL FORCE COEF. \\
\end{align*} \]

\[ \begin{align*}
PITCH MOMENT COEF. \\
NORMAL FORCE COEF. \\
\end{align*} \]

\[ \begin{align*}
NCP & \quad CRL. FROM NOSE \\
\end{align*} \]

\[ \begin{align*}
\text{ANDEG.} & \quad \text{DEG.} \\
-12 & \quad -9 \\
-6 & \quad -3 \\
0 & \quad 3 \\
6 & \quad 9 \\
12 & \quad 15 \\
18 & \quad \\
\end{align*} \]

\[ \text{CONFIG} = 5.40 \quad \text{RUN} = 41. \]

121:
5 CAL. A-N SPINNER ROCKET. SQUARE BOATTAIL W/FINS. STRAIGHT MACH 0.89 ROLL 45 DEG. R(DIA) 0.48 X 10^6

CONFIG: 5.40  RUN: 44
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7x10 FT. TRANSONIC WIND TUNNEL:
5 CAL. R-N SPINNER ROCKET, SQUARE BOATTAIL WING, CANTED
MACH 0.50
R(DIA) 1.05 x 10^6

PITCH MOMENT COEF., SINC NORMAL FORCE COEF.

CONFIG = 5.50 RUN = 21.
ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.

CONFIG  5.50 RUN  20.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL

5 CAL. A-N SPINNER ROCKETS, SQUARE BOATTAIL W/FINS, CANTED
MACA 0.50
PD/V 0.66
R(DIR) 1.06 x 10^6

ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.

CONFIG: 5.50
RUN: 20.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL W/FINS, CANTED
MACH 0.90
RADIUS 1.39 X 10^6

\[ C_N, C_M, C_{\text{pitch}} \text{ and normal force coeff.} \]

\[ \text{Pitch moment coef.} \]

\[ \text{Normal force coeff.} \]

\[ \text{NCP, cal. from nose} \]

\[ \text{Angle of attack, deg.} \]

CONFIG = 5.50 RUN = 23

126
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7x10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL W/FINS, CANTED
MACH 0.90 PD/V 0.19 R(DIA) 1.40 X 10^6

ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.

CONFIG = 5.50 RUN = 22.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL W/FINS, CANTED
MACH 0.90  PD/V 0.38  R(DIR) 1.40 X 10^6

ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.

CONFIG = 550  RUN = 22.

128
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. 6-N SPINNER ROCKET, TRIANGULAR BOATTAIL, STRAIGHT
MACH 1.75
R/DIA: 0.92 X 10^-6

PITCH MOMENT COEFF. AND NORMAL FORCE COEFF.

PITCH MOMENT COEFF.
NORMAL FORCE COEFF.

CAL. FROM NOSE

ANGLE OF ATTACK, DEG.

CONFIG: 5.60 RUN: 7.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET. TRIANGULAR BOATTAIL, STRAIGHT
MACH 1.75 PD/V 0.24 R(DIA) 0.92 X 10^6

† CONFIG = 5.60 RUN = 7.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, ESL
5 CAL. A-N SPINNER ROCKET, TRIANGULAR BOATTAIL, STRAIGHT
MACH 2.50
RADIUS 0.04 X 10^-6

[Graph showing pitch moment coefficients and normal force coefficients versus angle of attack.]

CONFIG 5.64 RUN 8.

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U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, TRIANGULAR BORNTAIL, STRAIGHT
MACH 2.50       PD/V 0.27       R(DIA) 0.94 X 10^6

CONFIG 5.60  RUN  8.

132
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, TRIANGULAR BERTAIL, STRAIGHT
MACH 4.00
RADIUS 0.65 X 10^6

CONFIG 5.60  RUN  9.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
6 CAL. A-N SPINNER ROCKET, TRIANGULAR BOATTAIL, STRAIGHT
MACH 4.00    PD/V 0.24    R(DIA) 0.65 X 10⁶

\[
\begin{align*}
&\text{CNP} \\
&\text{CMP} \\
&\text{MAGNUS MOMENT COEF. AND MAGNUS FORCE COEF.} \\
\end{align*}
\]

\[
\begin{align*}
&\text{MCP} \\
&\text{CAL. FROM NOSE} \\
\end{align*}
\]

\[
\begin{align*}
\text{ANGLE OF ATTACK, DEG.} \\
\end{align*}
\]

CONFIG = 5.60    RUN = 9.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WING TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, TRIANGULAR BOATTAIL, LANTED
MACH 1.75
R(DIA) 0.44 X 10^-6

 CONFIG: 5.70  RUN: 1.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. R-N SPINNER ROCKET, TRIANGULAR BOATTAIL, CANTED
MACH 1.75
FD/V 0.26
R(DIA) 0.94 X 10^6

THESE DATA MUST BE COMBINED WITH ZERO SPIN SIDE FORCE AND
YAWING MOMENT ON NEXT PAGE TO OBTAIN C_N AND C_M.

CONFIG = 5.70 RUN = 1.
SIDE FORCE AND YAWING MOMENT AT ZERO SPIN

5 cal. A-N with Canted Triangular Boattail
Mach 1.75  \( R_d = 0.94 \times 10^6 \)

\[ C_y \]

\[ C_n \]

\[ \text{ANGLE OF ATTACK} \sim \text{DEG.} \]
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, TRIANGULAR BOATTAIl, CANTED
MACH 2.50 PD/V 0.28 R(DIA) 0.95 X 10^6

These data must be combined with zero spin side force and
yawing moment on next page to obtain \( C_{mp} \) and \( C_{mp} \).

CONFIG 6.70 RUN = 2.
SIDE FORCE AND YAWING MOMENT AT ZERO SPIN

5 cal. A-N with Canted Triangular Boattail
Mach 2.5
R_d 0.95 x 10^6

![Graph showing side force and yawing moment vs. angle of attack.](graph.png)
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WIND TUNNELS BRANCH, EBL
5 CAL. 9-N SPINNER ROCKET, TRIANGULAR BOATTAIL, CANTED
MACH 4.00
R(DIA) 1.00 X 10^6

CONFIG: 5.7C RUN: 3.
THESE DATA MUST BE COMBINED WITH ZERO SPIN SIDE FORCE AND YAWING MOMENT ON NEXT PAGE TO OBTAIN $C_{pa}$ AND $C_{np}$.

CONFIG = 5.70  RUN = 3.
SIDE FORCE AND YAWING MOMENT AT ZERO SPIN

5 cal. A-N with Canted Triangular Boattail
Mach 4.0  \[ R_d 1 \times 10^6 \]

\[ C_y \]

\[ C_n \]

\[ \text{ANGLE OF ATTACK \sim DEG.} \]
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WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, CRUCIFORM BOATTAIL, STRAIGHT
MACH 1.75
R(DIA) 0.91 X 10^6

CONFIG 5.90 RUN 13.
144
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. R-N SPINNER ROCKET, CRUCIFORM BOATTAIL, STRAIGHT
MACH 1.75  PD/V 0.26  R(DIA) 0.91 x 10^6

CONFIG 5.90  RUN 13.
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WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, CRUCIFORM BOATTAIL, STRAIGHT
MACH 2.50
R(DIA) 0.94 X 10^6

PITCH MOMENT COEF. AND NORMAL FORCE COEF.

-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2

NCP
CAL. FROM NOSE

-12 -9 -6 -3 0 3 6 9 12 15 18

ANGLE OF ATTACK, DEG.

CONFIG 5.90 RUN 14.
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WIND TUNNELS BRANCH, FBL
5 CAL. R-N SPINNER ROCKET, CRUCIFORM BOATTAIL, STRAIGHT
MACH 2.50      PD/V 0.21      R(DIA) 0.94 x 10^6

CONFIG = 5.90      RUN = 14.      147
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, ESL
5 CAL. A-N SPINNER ROCKET, CRUCIFORM BOATTAIL, STRAIGHT
MACH 4.00
R(DIA) 0.99 X 10^6

PITCH MOMENT COEF.
NORMAL FORCE COEF.

ANGLE OF ATTACK, DEG.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, CRUCIFORM BOATTAIL, STRAIGHT
MACH 4.00 PD/V 0.18 R(DIA) 0.99 x 10^-6

0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20

CNP
MAGNUS MOUNT CNP. AND MAGNUS FORCE COEF.

MCP
CM. FROM NOSE

CM
CNP

-12 -9 -6 -3 0 3 6 9 12 15 18
ANGLE OF ATTACK, DEG.

CONFIG= 5.90 RUN= 15.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, CSL
5 CAL. A-N SPINNER ROCKET, CRUCIFORM BOATTAIL, CANTED
MACH 1.75
REDO: C.82 X 10^5

pitch moment coeff.

ormal force coeff.

CONFIG = 5.90 RUN = 4
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL

5 CAL. A-N SPINNER ROCKET, CRUCIFORM BOATTAIL, CANTED
MACH 1.75  PD/V 0.26  R(DIA) 0.82 X 10^6

THESE DATA MUST BE COMBINED WITH ZERO SPIN SIDE FORCE AND
YAWING MOMENT ON NEXT PAGE TO OBTAIN C_{Np} AND C_{mp}.

CONFIG= 5.90  RUN=  4.

151
SIDE FORCE AND YAWING MOMENT AT ZERO SPIN

5 cal. A-N with Canted Cruciform Boattail
Mach 1.75 \( R_d \ 0.82 \times 10^6 \)

-0.02

\( C_{y_0} \)

0.02

-0.02

\( C_{n_0} \)

-12 -8 -4 0 4 8 12 16

ANGLE OF ATTACK ~ DEG.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. F-N SPINNER ROCKET. CRUCIFORM BOATTAIL. CANTED
MACH 2.50
R(DIA): 0.94 X 10^2

PITCH MOMENT COEF.
X NORMAL FORCE COEF.

CAL. FROM NOSE

ANGLE OF ATTACK, DEG

CONF: 5.90 RUN: 5

153
THESE DATA MUST BE COMBINED WITH ZERO SPIN SIDE FORCE AND YAWING MOMENT ON NEXT PAGE TO OBTAIN $C_{n_{pa}}$ AND $C_{m_{pa}}$. 

CONFIG = 5-yr  RUN = 5.
SIDE FORCE AND YAWING MOMENT AT ZERO SPIN

5 cal. A-N with Canted Cruciform Boattail
Mach 2.50
Rd 0.94 x 10^6

ANGLE OF ATTACK ~ DEG.
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, (CLOCIFORM SEAT TAIL), CONTOUR
MACH 4.00
RIGID: C.65 X 10^6

PITCH MOMENT COEF. AND NORMAL FORCE COEF.

PITCH MOMENT COEF.
NORMAL FORCE COEF.

CONFIG: 5.90 RUN: 6

156
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. R-N SPINNER ROCKET, CRUCIFORM BOATTAIL, CANTED
MACH 4.00 PD/V 0.18 R(DIA) 0.65 X 10^6

ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.

CONFIG 5.90 RUN 6.
LIST OF SYMBOLS

\[ C_D = \frac{\text{Drag}}{\frac{1}{2} \rho V^2 S} \]  positive direction is aft

\[ C_{D_0} \]  zero angle of attack drag coefficient

\[ C_{D_\alpha^2} \]  drag coefficient slope due to angle of attack

\[ (\text{from } C_D = C_{D_0} + C_{D_\alpha^2} \alpha^2) \]

\[ C_\ell_p \]  roll damping moment coefficient--negative moment tends to decrease spin

\[ C_\ell_\delta \]  roll moment coefficient due to fin cant--positive moment tends to increase spin

\[ C_m \]  Pitching Moment

\[ \frac{1}{2} \rho V^2 S d \]

moment center is 0.6 \( \ell \) calibers from nose.

Positive moment is due to positive normal force ahead of the moment center.

\[ C_m \]  at \( \alpha = 0^\circ \) per radian

\[ \frac{d C_m}{d \alpha} \]

\[ C_m_\alpha \]

\[ C_m_p \]  Magnus Moment

\[ \frac{1}{2} \rho V^2 S d \frac{\text{d}}{\text{d} V} \]

moment center is 0.6 \( \ell \) calibers from nose.

Positive moment is due to positive Magnus force ahead of moment center.

\[ \frac{d C_m_p}{d \alpha} \]

\[ C_m_p_\alpha \]

\[ C_m_< \]  pitching moment

\[ \frac{d}{d \alpha} \]

\[ C_m_< \]

\[ C_m_q \]  Damping Moment

\[ \frac{1}{2} \rho V^2 S \frac{q_t d}{\text{d} V} \]

\[ C_N \]  Normal Force

\[ \frac{1}{2} \rho V^2 S \]  positive direction is up

\[ C_N \]

\[ \frac{d C_N}{d \alpha} \]

\[ C_N_\alpha \]  at \( \alpha = 0^\circ \) per radian

159
LIST OF SYMBOLS (Continued)

\[ C_{N_p} = \frac{\text{Magnus Force}}{\frac{1}{2} \rho V^2 S \frac{pd}{V}} \]

\[ \frac{d C_{N_p}}{d \alpha} \text{ at } \alpha = 0^\circ \text{ per radian} \]

\[ C_{n_0} \]

Magnus or side moment at zero spin

\[ C_{Y_0} \]

Magnus or side force at zero spin

\[ d \]

body diameter and reference length

\[ I_x \]

axial moment of inertia

\[ I_y \]

transverse moment of inertia

\[ k_x \]

axial radius of gyration

\[ k_y \]

transverse radius of gyration

\[ M_{CP} \]

Magnus force center of pressure

\[ N_{CP} \]

normal force center of pressure

\[ p \]

body axial spin rate, rad/sec (positive is clockwise looking upstream)

\[ q_t \]

complex transverse angular velocity

\[ R_d \]

Reynolds number based on d

\[ S \]

body area = \( \frac{\pi d^2}{4} \)

\[ 2 \left( C_{L_{\alpha}} + k_x^{-2} C_{m_{p_{\alpha}}} \right) \]

\[ S_d \]

dynamic stability = \( \frac{C_{L_{\alpha}} - C_D - k_y^{-2} (C_{m_q} + C_{m_{\alpha}})}{C_{L_{\alpha}} - C_D - k_x^{-2} (C_{m_q} + C_{m_{\alpha}})} \)
LIST OF SYMBOLS (Continued)

\[ S_g = \frac{\left( \frac{I_x}{I_y} \frac{pd}{V} \right)^2}{2\rho S d^3 \frac{I_y}{I_x} C_{m_{\alpha}}} \]

- \( V \): free stream velocity
- \( \alpha \): angle of attack
- \( \delta \): cant angle of fin or twisted surface
- \( \rho \): free stream air density

\[ \delta \Gamma C_{x_{\delta}} + \frac{pd}{V} \frac{C_{x_{\delta}}}{p} \frac{1}{2} \rho \frac{V^2}{S} d = \text{Roll Moment} \]
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