MEMORANDUM REPORT ARBRL-MR-03023

EFFECT OF NEAR-ZERO SPIN ON INSTABILITY
OF CONTROLLED PROJECTILES IN
ASCENDING OR DESCENDING FLIGHT

Charles H. Murphy
James W. Bradley

May 1980

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

Approved for public release; distribution unlimited.
Destroy this report when it is no longer needed.
Do not return it to the originator.

Secondary distribution of this report by originating or sponsoring activity is prohibited.

Additional copies of this report may be obtained from the National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22151.

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

The use of trade names or manufacturers' names in this report does not constitute endorsement of any commercial product.
**Title:**
EFFECT OF NEAR-ZERO SPIN ON INSTABILITY OF CONTROLLED PROJECTILES IN ASCENDING OR DESCENDING FLIGHT

**Author(s):**
Charles H. Murphy and James W. Bradley

**Performing Organization Name and Address:**
U.S. Army Ballistic Research Laboratory
(ATTN: DRDAR-BLL)
Aberdeen Proving Ground, MD 21005

**Report Date:**
May 1980

**Distribution Statement:**
Approved for public release; distribution unlimited.

**ABSTRACT:**
Lloyd and Brown have shown that constant-amplitude horizontal and vertical side forces applied to a spinning projectile can cause dynamic instability. A subsequent ARRADCOM report removed some of the limitations of the Lloyd-Brown work and gave somewhat more general results. Unfortunately, these results were applied in the report to a case for which they were unsuitable: a nonspinning statically stable missile. The present report derives correct results for the zero-spin case and shows that the results of the earlier report are valid for spin rates greater than about five times the resonant spin value.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. INTRODUCTION.</td>
<td>5</td>
</tr>
<tr>
<td>II. GENERAL THEORY.</td>
<td>5</td>
</tr>
<tr>
<td>III. SOLUTION FOR SMALL SPIN</td>
<td>8</td>
</tr>
<tr>
<td>IV. SOLUTION FOR ZERO SPIN</td>
<td>9</td>
</tr>
<tr>
<td>V. SUMMARY</td>
<td>11</td>
</tr>
<tr>
<td>REFERENCES.</td>
<td>13</td>
</tr>
<tr>
<td>LIST OF SYMBOLS</td>
<td>15</td>
</tr>
<tr>
<td>DISTRIBUTION LIST</td>
<td>19</td>
</tr>
</tbody>
</table>
I. INTRODUCTION

In 1977, Lloyd and Brown\(^1\) investigated the feasibility of controlling a 105mm spinning projectile by means of horizontal and vertical forces. Their numerical calculations yielded the surprising result that an applied constant-amplitude yaw moment could cause dynamic instability. This result was then explained theoretically by the influence of a nonlinear term in \(\frac{1}{\rho}p\), the fixed-plane coordinate system spin rate.

The Lloyd and Brown work was limited to large stability factors, neglected spin and density variations and incompletely considered gravity. Reference 2 removed these limitations and thereby gave somewhat more general results as well as a more elegant derivation. Unfortunately, the relations of Reference 2 were applied there to the case of a nonspinning statically stable missile. Although these relations are valid for statically stable missiles with spin rates that are large in comparison with the resonance spin, they are definitely invalid for zero and "near-zero" spin. It is the purpose of this memorandum report to give a more rigorous derivation of the relations of Reference 2 and to obtain the correct equations for a statically stable missile with zero spin.

II. GENERAL THEORY

Equation (3.8) of Reference 2 can be written in the form:

\[
\ddot{\xi}'' + (H - i P)\dot{\xi}' - (M + i PT)(\ddot{\xi} - \ddot{\xi}_e) = - 2 i E[\dot{\theta}'' + (H - i P)\dot{\theta}']
\]

(2.1)


where

\[ E = \frac{(a/2)\dot{\xi}_e \tan \theta_e}{\alpha_e} \]

\[ \dot{\xi}_e = -C/(M + i PT) \]

\[ a = [\gamma_e + \dot{\alpha}_e \tan \theta_e]^{-1} \]

and the other symbols are defined in the List of Symbols.

The right-hand side of Equation (2.1) is the forcing function due to \( \phi_{FP} \), linearized with respect to the equilibrium angle \( \dot{\xi}_e \) produced by the control moment. Since

\[ \dot{\beta} - \dot{\beta}_e = (1/2)[\dot{\xi} - \dot{\xi}_e + \ddot{\xi} - \dot{\xi}_e] \quad (2.2) \]

\( \dot{\beta} \) can be eliminated from Equation (2.1). The result has a quite simple form if \( \dot{\xi}_e \) is assumed to be constant:

\[ \dddot{\xi} + (H - i P)\dot{\xi}' - (1 - i \dot{E})(M + i PT)(\dot{\xi} - \dot{\xi}_e) \]

\[ = -i \dot{E}[\dddot{\xi}' + (H - i P)\dot{\xi}'] \quad (2.3) \]

where

\[ \dot{\xi} = \dot{E}/(1 + i E) \]

Equation (2.3) is a second-order complex equation with constant coefficients, but it involves \( \xi \) as well as \( \xi' \). Equations of this kind were solved in Reference 3 by assuming a solution of the form:

\[ \dot{\xi} = \dot{\xi}_e + k_e e^{\psi_1 z} + k_2 e^{\psi_2 z} + k_3 e^{\psi_1 z} + k_4 e^{\psi_2 z} \quad (2.4) \]

where \( k_j \) and \( \psi_j \) are complex constants:

\[ k_j = K_j e^{i\phi_j} \]

\[ \psi_j = \lambda_j + i \phi_j \]

If Equation (2.4) is substituted in Equation (2.3) and the coefficients of the four exponentials are set equal to zero, there results

\[
\begin{align*}
\frac{\ddot{k}_j + 3}{k_j} &= \frac{F_j + i M_e}{-i[E F_j + M_e]} \\
&= \frac{i \left\{ \ddot{E}[1_j + 2 i P(\psi_j + T)] + \ddot{M}_e \right\}}{F_j - i \ddot{M}_e + 2 i P(\psi_j + T)} \\
\end{align*}
\]

(2.5)

\( j = 1, 2 \)

where \( F_j = \psi_j^2 + (H - i P)\psi_j - M - i P T \).

\( M_e = \ddot{E}(M + i P T) \)

For \( E = 0 \), \( k_4 = k_5 = 0 \) and the equation \( F_j = 0 \) is the usual quadratic equation for the epicyclic frequencies and damping rates. We wish to find the effect of small nonzero \( E \). Equation (2.5) can be written in the following form, where \( \psi_j + T \) has been approximated by \( i \psi_j' \).

\[
F_j + i M_e = \frac{\ddot{E}(F_j - 2 P \psi_j') + \ddot{M}_e}{F_j - 2 P \psi_j' - i \ddot{M}_e} \quad (2.6)
\]

A first approximation for \( F_j \) can be obtained by setting the small right side of Equation (2.6) equal to zero.

\[
F_j = -i M_e \quad (2.7)
\]

A better approximation for \( F_j \) now follows from Equation (2.6) by replacing \( F_j \) on the right side by \( -i M_e \) and neglecting \( \tau^2 \) terms compared to \( E \) terms.
\[ F_j = M_e \left\{ -i + \frac{-\bar{E} [2 \, P \, \phi'_j - M + i \, PT]}{2 \, P \, \phi'_j + i \, (M_e - \bar{M}_e)} \right\} \quad (2.8) \]

For this approximation,

\[ \frac{k_{j+3}}{k_j} = \frac{-i \, \bar{E} \, (2 \, P \, \phi'_j - M - i \, PT)}{2 \, P \, \phi'_j - i \, (M_e + \bar{M}_e)} \quad (2.9) \]

### III. SOLUTION FOR SMALL SPIN

For small spin, the PT term in Equations (2.8 - 9) can be omitted and these equations reduce to

\[ F_j = \bar{E} \, M \left\{ -i + \frac{-\bar{E} \, (1 - R_j)}{1 + i \, (\bar{E} + \bar{E}) \, R_j} \right\} \quad (3.1) \]

\[ \frac{k_{j+3}}{k_j} = \frac{-i \, \bar{E} \, (1 - R_j)}{1 - i \, (\bar{E} + \bar{E}) \, R_j} \quad (3.2) \]

where \( R_j = M/(2 \, P \, \phi'_j) \).

The iterative process that produced Equation (3.1) is valid only if the absolute value of the second term in that equation is smaller than the absolute value of the first term. For small \(|\bar{E}|\), this is the case if \(|R_j|\) is less than, say, unity (a conservative upper bound):

\[ |R_j| < 1 \quad (3.3) \]

This condition is always satisfied for the rapidly spinning shell of Reference 1, but its applicability to a slowly spinning finner must be analyzed by use of the concept of resonance spin.

Resonance spin, \( \phi'_\text{reson} \), is defined by the relations

\[ \phi'_\text{reson} = \phi'_1 = - \phi'_2 = \sqrt{\frac{M}{2}} \quad (3.4) \]
Relation (3.3) assumes a very simple form in terms of resonant spin.

\[ \frac{\phi' / \phi_{\text{reson}}}{l} \geq \frac{1}{2I_x} \quad (3.5) \]

Moment of inertia ratios can be as high as 10:1. Thus, relation (3.5) would be satisfied for spins in excess of five times resonance.

When condition (3.5) is satisfied, the magnitudes of \( k_4 \) and \( k_5 \) are given in terms of \( k_1 \) and \( k_2 \) by Equation (3.2) and are small for small \( |\dot{\theta}| \). For a trim of 12° and a maximum climb or descent angle of 45°, \(|\dot{\theta}| \) would be about 0.2. For these conditions, \( k_4 \) and \( k_5 \) could be neglected and the motion approximated by a tricycle. This is what was done in Reference 2 and Equation (2.7) yields the frequencies and damping rates of that report.

For spin rates lower than five times resonant spin, Equation (2.7) loses validity and should be used with caution. This was not done in Reference 2 and erroneous results were given for zero spin.

IV. SOLUTION FOR ZERO SPIN

For \( P = 0 \), Equation (2.5) requires that

\[ (F_j - b M)F_j = 0 \quad (4.1) \]

where

\[ b = (\hat{a}_e \tan \theta_e)/\gamma_c \]

If \( \hat{a}_e \) is not zero, Equation (4.1) has two distinct roots:

\[ F_1 = 0, \ b M \quad (4.2) \]

The four roots of these two quadratic equations are the \( \Psi_1, \bar{\Psi}_1, \Psi_2, \bar{\Psi}_2 \) of Equation (2.4). If we identify \( \Psi_1 \) and \( \bar{\Psi}_1 \) as the roots of the first of these quadratic equations and \( \Psi_2 \) and \( \bar{\Psi}_2 \) as roots of the second, then

\[ F_1 = 0, \ F_2 = b M \quad (4.3) \]
For these roots, Equation (2.5) reduces to

\[ k_4 = -k_1 \]  \hspace{1cm} (4.4)

and

\[ k_5 = -\left(\frac{\xi_e}{\xi_e}\right)k_2 \]  \hspace{1cm} (4.5)

Hence the solution to Equation (2.3) for \( P = 0 \) and \( \hat{\alpha}_c \neq 0 \) is

\[ \hat{\xi} = \xi_e + K_1 \left( e^{i\phi_1} - e^{-i\phi_1} \right) + K_2 \left[ e^{i\phi_2} - \left( \frac{\xi_e}{\xi_e} \right) e^{-i\phi_2} \right] \]  \hspace{1cm} (4.6)

where, from Equation (4.3)

\[ K_j = K_{j0} \exp(-Hs/2) \]

and (ignoring a small \( H^2 \) term)

\[ \phi_1' = [-M]^{1/2} \]

\[ \phi_2' = -[-(1 + b)M]^{1/2} \]

For the special case \( \hat{\alpha} = 0 \) (which occurs when the fixed-plane transverse control moment has no horizontal component), Equation (4.1) has repeated roots: \( F_1 = F_2 = 0 \). Equation (2.4) is inadequate to handle this situation. Instead, we must assume a solution of the form

\[ \hat{\xi} = \beta_e + (k_1 + k_4s)e^{1s} + (k_2 + k_5s)e^{1s} \]  \hspace{1cm} (4.7)
Direct substitution in Equation (2.3) yields the relations:

\[ k_4 = - k_5 = \left( \frac{M \hat{\beta}_e \tan \theta_e}{4 \gamma_e \phi'_1} \right) (k_1 + k_2) \quad (4.8) \]

Hence, for \( P = 0 \) and \( \hat{\alpha}_e = 0 \), we have

\[ \hat{\xi} = \hat{\beta}_e + K_1 e^{i \phi_1} + K_2 e^{i \phi_2} \left( \frac{i M \hat{\beta}_e \tan \theta_e}{2 \gamma_e \phi'_1} \right) (K_1 \sin \phi_1 - K_2 \sin \phi_2) s \]

where

\[ \phi'_1 = - \phi'_2 = [-M]^{1/2} \]

We see that in both zero-spin solutions, (4.6) and (4.9), \( \hat{\xi}_e \) has no effect on the damping rates and \( \hat{\theta}_e \) has no effect on the frequencies. A nonzero \( \hat{\alpha}_e \) will effect just one of the frequencies; zero \( \hat{\alpha}_e \) will cause secular terms to appear in the solution.

V. SUMMARY

1. The relations given in Reference 2 are valid for gyroscopically stable missiles for \( 1 < s / g \ll \infty \) and for statically stable missiles for which \( \phi' / \phi'_{reson} > 5 \).

2. For statically stable missiles with lower spin rates, the motion is quite complex and should be studied by numerical simulation.
REFERENCES


### List of Symbols

- **a**
  
  \[ [\gamma_e + \dot{\gamma}_e \tan \theta_e]^{-1} \]

- **b**
  
  \[ \dot{\gamma}_e \tan \theta_e / \gamma_e \]

- **C**
  
  \[ i \gamma k^{-2} (m V^2)^{-1} \times \text{(fixed-plane system complex control moment)} \]

- **C_D**
  
  \[ \frac{\text{drag force}}{(1/2) \rho S V^2} \]

- **C_L_a**
  
  \[ \frac{\text{lift force}}{(1/2) \rho S V^2 \delta} \]

- **C_M_p_a**
  
  \[ \frac{\text{Magnus moment}}{(1/2) \rho S \delta V^2 \phi' \delta} \]

- **C_M_q + C_M_a**
  
  \[ \frac{\text{sum of the damping moments}}{(1/2) \rho S \delta V^2 (q^2 + r^2)^4} \]

- **C_M_a**
  
  \[ \frac{\text{static moment}}{(1/2) \rho S \delta V^2 \delta} \]

- **E**
  
  \[ \frac{E}{1 + i E} \]

- **E**
  
  \[ \frac{E}{1 + i E} \]

- **F_j**
  
  \[ \psi_j - (H - i P) \psi_j - M - i P T \]

- **H**
  
  \[ \frac{\rho S m \delta}{2m} \left[ \gamma C_L_a - C_D - \frac{m^2}{I_y} (C_M_q + \gamma C_M_a) \right] \]

- **I_x, I_y**
  
  \[ \text{axial and transverse moments of inertia} \]

- **K_j**
  
  \[ K_j = e^{j \lambda_j} \]

- **K_j^0**
  
  \[ |K_j|^\lambda_j \]

- **K_j^0**
  
  \[ |K_j|^\lambda_j \]

- **K_j^0**
  
  \[ |K_j|^\lambda_j \]

- **K_j^0**
  
  \[ |K_j|^\lambda_j \]

- **K_j^0**
  
  \[ |K_j|^\lambda_j \]
LIST OF SYMBOLS
(Continued)

\[ k_j \bigg( K_j e^{i j_0} \bigg) \], the j-th modal arm at \( s = 0 \)
\( (j = 1, 2, 4, 5) \)

\( l \)
reference length

\[ M \gamma \left( \frac{\rho S \xi^3}{2 I_y} \right) C_{\alpha \alpha} \]

\( M_e \)
\( (M + i P T) \dot{\alpha} \)

\( P \)
\( (I_x / I_y) \psi' \)

\( p, q, r \)
missile spin, pitch and yaw rates in a missile-fixed system

\( R_j \)
\( M / (2P \psi' j) \)

\( S \)
reference area

\( s \)
nondimensional arc length along the trajectory

\( s_0 \)
\( P^2 / 4M, \) the gyroscopic stability factor

\[ T \gamma \frac{\rho S \xi}{2 \xi} \left[ C_{\alpha \alpha} + \frac{m \xi^2}{I_x} C_{\alpha \alpha} \right] \]

time

\( u, v, w \)
velocity components in a missile-fixed system

\( V \)
magnitude of the velocity

\( \alpha, \beta \)
angles of attack and side-slip in a fixed-plane system

\( \alpha_e, \beta_e \)
imaginary and real parts of \( \dot{\alpha}_e \)
LIST OF SYMBOLS
(Continued)

\( \gamma_e \)  
equilibrium value of \((u/V)\)

\( \delta \)  
\(|\tilde{\epsilon}|\)

\( \theta_e \)  
equilibrium value of the angle between the missile's axis and the horizontal

\( \lambda_j \)  
\( \frac{K'_j}{K_j} \quad (j = 1, 2) \)

\( \xi \)  
\( \left( \frac{v + iw}{V} \right)^{i(\phi - \phi_{FP})} = \tilde{\beta} + i \tilde{\alpha} \)

\( \tilde{\xi}_e \)  
\(-\frac{C}{(M + i PT)}, \text{ the equilibrium value of } \xi\)

\( \rho \)  
air density

\( \phi_j \)  
\( \phi_{j0} + \phi_j's \quad (j = 1, 2) \)

\( \phi' \)  
\( pt/V \)

\( \phi_j' \)  
turning rate of the \( j \)-th modal arm \((j = 1, 2)\)

\( \phi'_{\text{reson}} \)  
resonance value of \( \phi' \)

\( \phi_{FP} \)  
spin rate of the fixed-plane coordinate system

\( \psi_j \)  
\( \lambda_j + i \phi_j' \quad (j = 1, 2) \)

Superscripts

\( (\cdot) \)  
\( d(\cdot)/dt \)

\( (\cdot)' \)  
\( d(\cdot)/ds = (\cdot)_{\text{FP}}/V \)

\( (\cdot)_{\text{FP}} \)  
fixed-plane value of \( (\cdot) \)

\( (\cdot)^{\dagger} \)  
complex conjugate
LIST OF SYMBOLS
(Continued)

Subscript

( )e

steady-state equilibrium value due to control moment
<table>
<thead>
<tr>
<th>No. of Copies</th>
<th>Organization</th>
<th>No. of Copies</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Commander</td>
<td>1</td>
<td>Director</td>
</tr>
<tr>
<td></td>
<td>Defense Technical Info Center</td>
<td></td>
<td>US Army Air Mobility Research</td>
</tr>
<tr>
<td></td>
<td>ATTN: DDC-DDA</td>
<td></td>
<td>&amp; Development Laboratory</td>
</tr>
<tr>
<td></td>
<td>Cameron Station</td>
<td></td>
<td>Ames Research Center</td>
</tr>
<tr>
<td></td>
<td>Alexandria, VA 22314</td>
<td></td>
<td>Moffett Field, CA 94035</td>
</tr>
<tr>
<td>1</td>
<td>Commander</td>
<td>1</td>
<td>Commander</td>
</tr>
<tr>
<td></td>
<td>US Army Materiel Development &amp; Readiness Command</td>
<td></td>
<td>US Army Communications Research</td>
</tr>
<tr>
<td></td>
<td>ATTN: DRCMD-ST</td>
<td></td>
<td>&amp; Development Command</td>
</tr>
<tr>
<td></td>
<td>5001 Eisenhower Avenue</td>
<td></td>
<td>ATTN: DRCO-PPA-SA</td>
</tr>
<tr>
<td></td>
<td>Alexandria, VA 22333</td>
<td></td>
<td>Fort Monmouth, NJ 07703</td>
</tr>
<tr>
<td>2</td>
<td>Commander</td>
<td>1</td>
<td>Commander</td>
</tr>
<tr>
<td></td>
<td>US Army Armament Research &amp; Development Command</td>
<td></td>
<td>US Army Electronic Research</td>
</tr>
<tr>
<td></td>
<td>ATTN: DRDAR-TSS</td>
<td></td>
<td>and Development Command</td>
</tr>
<tr>
<td></td>
<td>Dover, NJ 07801</td>
<td></td>
<td>Technical Support Activity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>ATTN: DELSD-L</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fort Monmouth, NJ 07703</td>
</tr>
<tr>
<td>4</td>
<td>Commander</td>
<td>1</td>
<td>Commander</td>
</tr>
<tr>
<td></td>
<td>US Army Armament Research &amp; Development Command</td>
<td></td>
<td>US Army Missile Command</td>
</tr>
<tr>
<td></td>
<td>ATTN: DRDAR-LCA-F, Mr. A. Loeb</td>
<td></td>
<td>ATTN: DRCMI-R</td>
</tr>
<tr>
<td></td>
<td>DRDAR-LCA-FA, Mr. S. Wasserman</td>
<td></td>
<td>Redstone Arsenal, AL 35809</td>
</tr>
<tr>
<td></td>
<td>DRDAR-LCA, Mr. W.R. Benson</td>
<td></td>
<td>Commander</td>
</tr>
<tr>
<td></td>
<td>DRDAR-LCU, Mr. A. Moss</td>
<td></td>
<td>US Army Missile Command</td>
</tr>
<tr>
<td></td>
<td>Dover, NJ 07301</td>
<td></td>
<td>ATTN: DRSMI-YDL</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Redstone Arsenal, AL 35809</td>
</tr>
<tr>
<td>1</td>
<td>Commander</td>
<td>1</td>
<td>Commander</td>
</tr>
<tr>
<td></td>
<td>US Army Armament Material Readiness Command</td>
<td></td>
<td>US Army Tank Automotive Research</td>
</tr>
<tr>
<td></td>
<td>ATTN: DRSAR-LEP-L, Tech Lib</td>
<td></td>
<td>&amp; Development Command</td>
</tr>
<tr>
<td></td>
<td>Rock Island, IL 61299</td>
<td></td>
<td>ATTN: DRDTA-UL</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Warren, MI 48090</td>
</tr>
<tr>
<td>1</td>
<td>Director</td>
<td>1</td>
<td>Commander</td>
</tr>
<tr>
<td></td>
<td>US Army ARRADCOM</td>
<td></td>
<td>US Army Yuma Proving Ground</td>
</tr>
<tr>
<td></td>
<td>Benet Weapons Laboratory</td>
<td></td>
<td>ATTN: STEYP-TMW, Mr. W.T. Vomocil</td>
</tr>
<tr>
<td></td>
<td>ATTN: DRDAR-LCB-TL</td>
<td></td>
<td>Yuma, AZ 85364</td>
</tr>
<tr>
<td></td>
<td>Watervliet, NY 12189</td>
<td></td>
<td>Commander</td>
</tr>
<tr>
<td>1</td>
<td>Commander</td>
<td>1</td>
<td>US Army Research Office</td>
</tr>
<tr>
<td></td>
<td>US Army Aviation Research and Development Command</td>
<td></td>
<td>ATTN: CRD-AA-EH</td>
</tr>
<tr>
<td></td>
<td>ATTN: DRSAV-E</td>
<td></td>
<td>P.O. Box 12211</td>
</tr>
<tr>
<td></td>
<td>P.O. Box 209</td>
<td></td>
<td>Research Triangle Park</td>
</tr>
<tr>
<td></td>
<td>St. Louis, MO 61366</td>
<td></td>
<td>NC 27709</td>
</tr>
</tbody>
</table>

19
<table>
<thead>
<tr>
<th>No. of Copies</th>
<th>Organization</th>
<th>No. of Copies</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Director</td>
<td>US Army TRADOC Systems Analysis Activity</td>
<td>1 Commander</td>
<td>Naval Weapons Center</td>
</tr>
<tr>
<td></td>
<td>ATTN: ATAA-SL, Tech Lib White Sands Missile Range NM 88002</td>
<td></td>
<td>ATTN: Code 233 China Lake, CA 93555</td>
</tr>
<tr>
<td>1 Commander</td>
<td>Naval Air Systems Command ATTN: AIR-604 Washington, DC 20360</td>
<td></td>
<td>Naval Research Laboratory ATTN: Tech Info Div Washington, DC 20375</td>
</tr>
<tr>
<td>3 Commander</td>
<td>Naval Ordnance Systems Command ATTN: ORD-0632 ORD-035 ORD-5524</td>
<td></td>
<td>Superintendent Naval Postgraduate School Monterey, CA 93940</td>
</tr>
<tr>
<td></td>
<td>Washington, DC 20360</td>
<td></td>
<td>ATATL (Tech Lib) Eglin AFB, FL 32542</td>
</tr>
<tr>
<td>1 Commander</td>
<td>Naval Air Development Center, Johnsville Warminster, PA 18974</td>
<td></td>
<td>AFDL Wright-Patterson AFB, OH 45433</td>
</tr>
<tr>
<td>1 Commander</td>
<td>David W. Taylor Naval Ship Research &amp; Development Ctr ATTN: Aerodynamics Laboratory Bethesda, MD 20084</td>
<td></td>
<td>ASD (ASAMCG) Wright-Patterson AFB, OH 45433</td>
</tr>
<tr>
<td>5 Commander</td>
<td>Naval Surface Weapons Center ATTN: Dr. Thomas Clare Dr. W.R. Chadwick Dr. W.G. Soper Dr. F. Moore Dr. T.R. Pepitone Dahlgren, VA 22448</td>
<td></td>
<td>Director National Aeronautics and Space Administration Ames Research Center ATTN: Dr. Gary Chapman Mr. A. Seiff Mr. Murray Tobak Tech Lib Moffett Field, CA 94035</td>
</tr>
<tr>
<td>1 Commander</td>
<td>Naval Surface Weapons Center ATTN: Code 730, Tech Lib Silver Spring, MD 20910</td>
<td></td>
<td>Director National Aeronautics and Space Administration George C. Marshall Space Flight Center ATTN: MS-1, Library Huntsville, AL 35812</td>
</tr>
<tr>
<td>No. of Copies</td>
<td>Organization</td>
<td>No. of Copies</td>
<td>Organization</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------</td>
<td>--------------</td>
<td>--------------</td>
</tr>
<tr>
<td>2</td>
<td>Director</td>
<td>1</td>
<td>Calspan Corporation</td>
</tr>
<tr>
<td></td>
<td>National Aeronautics and Space Administration</td>
<td></td>
<td>P.O. Box 235</td>
</tr>
<tr>
<td></td>
<td>Langley Research Center</td>
<td></td>
<td>Buffalo, NY 14221</td>
</tr>
<tr>
<td></td>
<td>ATTN: MS 185, Tech Lib</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dr. Clarence Young</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Langley Station</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hampton, VA 23365</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Director</td>
<td>1</td>
<td>General Electric Company</td>
</tr>
<tr>
<td></td>
<td>National Aeronautics and Space Administration</td>
<td></td>
<td>Armament Systems Department</td>
</tr>
<tr>
<td></td>
<td>Lewis Research Center</td>
<td></td>
<td>ATTN: Mr. Robert H. Whyte</td>
</tr>
<tr>
<td></td>
<td>ATTN: Tech Lib</td>
<td></td>
<td>Lakeside Avenue</td>
</tr>
<tr>
<td></td>
<td>21000 Brookpark Road</td>
<td></td>
<td>Burlington, VT 05401</td>
</tr>
<tr>
<td></td>
<td>Cleveland, OH 44135</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Director</td>
<td>1</td>
<td>Saber Industries Inc.</td>
</tr>
<tr>
<td></td>
<td>National Aeronautics and Space Administration</td>
<td></td>
<td>ATTN: Dr. G.V. Bull</td>
</tr>
<tr>
<td></td>
<td>Lewis Research Center</td>
<td></td>
<td>North Jay Road</td>
</tr>
<tr>
<td></td>
<td>ATTN: Tech Lib</td>
<td></td>
<td>P.O. Box 80</td>
</tr>
<tr>
<td></td>
<td>21000 Brookpark Road</td>
<td></td>
<td>North Troy, VT 05859</td>
</tr>
<tr>
<td></td>
<td>Cleveland, OH 44135</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Director</td>
<td>1</td>
<td>California Polytechnic State Univ</td>
</tr>
<tr>
<td></td>
<td>National Aeronautics and Space Administration</td>
<td></td>
<td>ATTN: Dr. John D. Nicolaides</td>
</tr>
<tr>
<td></td>
<td>Scientific and Technical Information Facility</td>
<td></td>
<td>Aeronautical Engineering Dept.</td>
</tr>
<tr>
<td></td>
<td>P.O. Box 8757</td>
<td></td>
<td>San Luis Obispo, CA 93401</td>
</tr>
<tr>
<td></td>
<td>Baltimore/Washington</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>International Airport, MD 21240</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Director</td>
<td>1</td>
<td>Stanford University</td>
</tr>
<tr>
<td></td>
<td>Jet Propulsion Laboratory</td>
<td></td>
<td>ATTN: Department of Aeronautical Engineering</td>
</tr>
<tr>
<td></td>
<td>ATTN: Tech Lib, Mr. Peter Joffe</td>
<td></td>
<td>Stanford, CA 94305</td>
</tr>
<tr>
<td></td>
<td>4800 Oak Grove Drive</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pasadena, CA 91103</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Director</td>
<td>1</td>
<td>University of California</td>
</tr>
<tr>
<td></td>
<td>Sandia Laboratories</td>
<td></td>
<td>ATTN: Professor E.V. Laitone</td>
</tr>
<tr>
<td></td>
<td>ATTN: Division 1342,</td>
<td></td>
<td>Berkeley, CA 94704</td>
</tr>
<tr>
<td></td>
<td>Mr. W.F. Hartman</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Division 1331,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mr. H.R. Vaughn</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mr. A.E. Hodapp</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Albuquerque, NM 87115</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Aerospace Corporation</td>
<td></td>
<td>University of Illinois</td>
</tr>
<tr>
<td></td>
<td>ATTN: Dr. Daniel Platus</td>
<td></td>
<td>Department of Aeronautical Engineering</td>
</tr>
<tr>
<td></td>
<td>2350 E El Segundo Avenue</td>
<td></td>
<td>ATTN: Prof. A.I. Ormsbee</td>
</tr>
<tr>
<td></td>
<td>El Segundo, CA 90245</td>
<td></td>
<td>Urbana, IL 61801</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>University of Virginia</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Department of Engineering Science &amp; Systems</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ATTN: Prof. Ira D. Jacobson</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Thornton Hall</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Charlottesville, VA 22904</td>
</tr>
</tbody>
</table>
DISTRIBUTION LIST

Aberdeen Proving Ground

Dir, USAMSAA
ATTN:   DRXSY-D
       DRXSY-MP, H. Cohen

Cdr, USATECOM
ATTN:   DRSTE-TO-F

Dir, Wpns Sys Concepts Team
Bldg. E3516, EA
ATTN:   DRDAR-ACW
USER EVALUATION OF REPORT

Please take a few minutes to answer the questions below; tear out this sheet and return it to Director, US Army Ballistic Research Laboratory, ARADCOM, ATTN: DRDAR-TSB, Aberdeen Proving Ground, Maryland 21005. Your comments will provide us with information for improving future reports.

1. BRL Report Number

2. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which report will be used.)

3. How, specifically, is the report being used? (Information source, design data or procedure, management procedure, source of ideas, etc.)

4. Has the information in this report led to any quantitative savings as far as man-hours/contract dollars saved, operating costs avoided, efficiencies achieved, etc.? If so, please elaborate.

5. General Comments (Indicate what you think should be changed to make this report and future reports of this type more responsive to your needs, more usable, improve readability, etc.)

6. If you would like to be contacted by the personnel who prepared this report to raise specific questions or discuss the topic, please fill in the following information.

   Name: ____________________________________________
   Telephone Number: ______________________________
   Organization Address: ______________________________