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FORM NO. 836 R4
ST. NO. 2629 5/81

NUMERICAL SIMULATIONS OF GUN-LAUNCHED KINETIC ENERGY PROJECTILES SUBJECTED TO ASYMMETRIC PROJECTILE BASE PRESSURE

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Summary - Three-dimensional numerical simulations were performed to determine the effect of an asymmetric base pressure on kinetic energy projectiles during launch. A matrix of simulations was performed in two separate launch environments. One launch environment represented a severe lateral load environment, while the other represented a nonsevere lateral load environment based on the gun tube straightness. The orientation of the asymmetric pressure field, its duration, the projectile's initial position, and the tube straightness were altered to determine the effects of each parameter. The pressure asymmetry translates down the launch tube to exit parameters and is not washed out by tube profile. Results from the matrix of simulations are presented.

INTRODUCTION

The work presented investigates the effect of an asymmetric base pressure on the M829 saboted long-rod projectile and the influence of base pressure asymmetry on projectile behavior inbore and on projectile motion near the muzzle. This asymmetry can affect the position of the projectile, not only immediately after ignition, but also during the flight down the gun tube.

Limited data were available on the duration, magnitude, and orientation of pressure asymmetries in the breech or on the back of the projectile. These data did indicate the possibility of differential pressures of 1 to 3% of the current base pressure at the back of the projectile during the first half of the pressure time history. Past experiments did not rule out or validate any pressure asymmetry. This study is based on the premise that there is an asymmetry and that mechanical and structural performance will change inbore and near muzzle exit.

The rational design of sabot/rod packages has evolved to include numerical simulations of many types, including beam models [1], static two-dimensional finite element analyses [2], and more detailed transient three-dimensional simulations [3,4]. The transient three-dimensional analyses include details that were experimentally proven to predict inbore projectile behavior and projectile flight characteristics near the muzzle of the gun. In the simulations, the M829 sabot/rod system was modeled in the M256 120-mm gun. The projectile entails the rod, sabot, obturator, fins, wind screen, and tip. The gun is free to recoil axially, and it includes a symmetric breech.

A matrix of 13 simulations was performed to determine the effect of asymmetric pressure on the projectile. The simulations were performed in two different launch tubes representing severe and nonsevere lateral acceleration environments. The methodology, system parameters, simulation matrix, results, and comparisons are presented in the following sections to provide insight into the effect of asymmetric base pressure on projectile performance.

SYSTEM PARAMETERS

System parameters for the M256 120-mm gun and M829 sabot/rod system include pressure histories, tube profiles, and projectile initial position. The M829 projectile consists of an aluminum sabot, a U3/4Ti alloy penetrator core, an aluminum windscreen with steel tip, aluminium fins, and a nylon obturator. The projectile has buttress grooves to engage the sabot with the rod. The M256 gun is the standard 120-mm gun used in the inventory. Dimensions for both systems are documented in "Axially Accelerated Saboted Rods Subjected to Lateral Forces." [3]

The gun tubes for this study were selected to simulate a severe and nonsevere lateral load environment. The severe lateral load environment is represented by the tube profile of SN81, and the nonsevere lateral load environment is represented by the tube profile of SN104. To determine the lateral tube profile for the tubes, droop and straightness profile were included. The M256 tube was modeled with the ABAQUS finite element code [5] and was subjected to gravity loads to determine the droop of the tube while stationary in the recoil mechanism. Results show that the tube droops 1.75 mm under its own weight. The tube profile is the straightness of the tube without the droop. Figure 1 shows the profile of both the tubes in the yz plane (up-down). The profile of SN81 has considerably more curvature than that of SN104. The curvature near the end of tube SN81 is encountered as the projectile is moving at high velocity where very little deviation exists in SN104. In the early portion of projectile travel, very little lateral motion can be seen in either tube. This region is the area most affected by the asymmetric base pressure. Both tubes have minimal deviation in the xz plane (left-right).

For this study, we defined an asymmetric base pressure case as having a 2% variation from the symmetric pressure case from one side of the projectile to the other. To accomplish this asymmetry, we assumed the pressure to have 99% of the symmetric pressure value on one side of the projectile and 101% of the symmetric pressure value on the other side of the projectile. One set of simulations assumes that the pressure asymmetry stops after the projectile begins to outrun the propellant grain; this occurs at approximately peak pressure (3.9 ms). Figure 2 illustrates the pressure time history for the asymmetric case studied. The 2% differential can be seen in the figure with the enlargement provided at the peak pressure. The top pressure trace on the enlargement represents the 101% base pressure loading, the center represents the 100% symmetric loading, and the lower represents the 99% base pressure loading. The breech pressure remained symmetric in all of the simulations as did the tube wall pressure. Because of the lack of data on when the asymmetric pressure front becomes symmetric, another, shorter period of asymmetry, was investigated with another set of simulations. A second pressure profile was chosen. This profile assumes that the base pressure asymmetry reverts to symmetry at 2.65 ms. This time corresponds to half the peak base pressure. The propellant bed compaction that occurs early on in the pressure time history might induce the conditions of asymmetry until 2.65 ms.

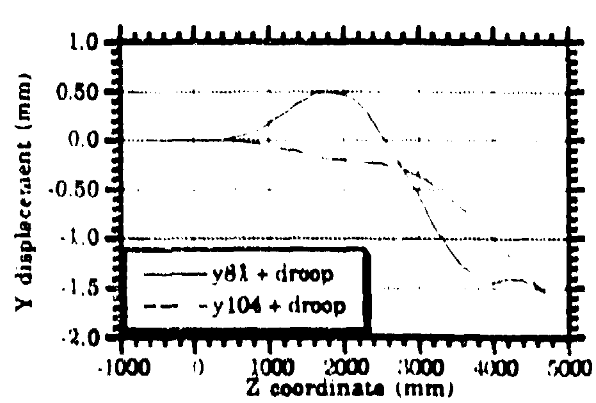

Fig. 1. Gun tube profiles for launch tubes SN81 and SN104.

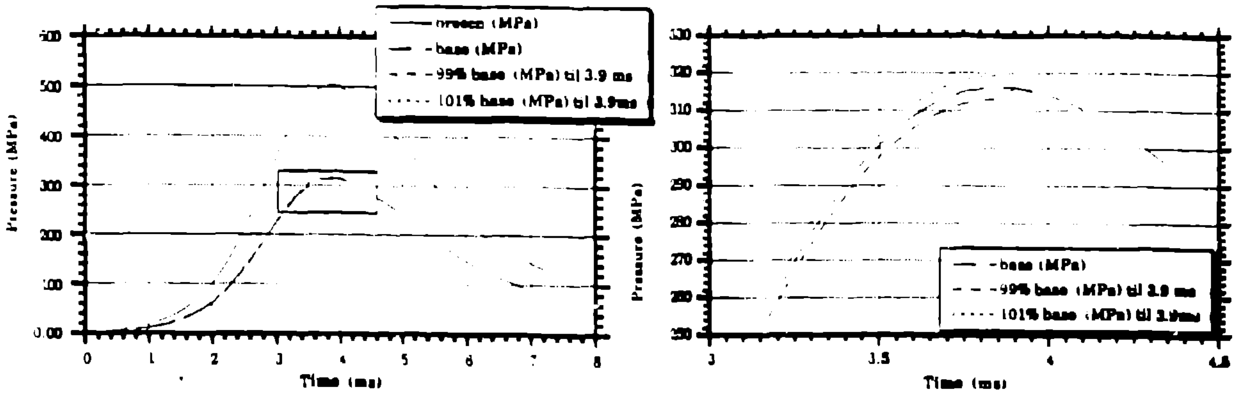

Fig. 2. Asymmetric base pressure history terminated at 3.9 ms.

NUMERICAL SIMULATIONS

<u>Numerical Models-</u> The M829 sabot/rod and M256 gun tube described in the previous section were modeled to ascertain the projectile performance differences encountered with the different gun tube profiles and the symmetric and asymmetric load profiles discussed therein. The components of the finite element mesh are shown in Fig. 3. The mesh was generated with the PATRAN code [6]. The mesh consists of 10,530 elements; 14,204 nodes; 20 pressure sets; with 4 separate pressure profiles representing the breech pressure, the symmetric base pressure, the 99% asymmetry profile, and the 101% asymmetry profile. The mesh incorporates sliding surfaces along the tube and projectile, 9 material groups, and boundary conditions that represent a symmetric recoil motion. Three versions of the mesh were generated to reflect the projectile initial conditions and the two tube profiles for SN81 and SN104. Tube profiles were input into the PATRAN output file by using the offset spline routine in GREPOS [7]. This program enables the user to specify a general spline and offset to alter an existing finite element mesh. The spline, in these cases, represents the centerline profile of the gun tube. Thirteen different simulations were completed.

The output from GREPOS was shipped from the VAX environment to the Cray Y-MP environment for the actual simulations. The PRONTO3D code [8] was used for the simulations. Each simulation required 403 minutes of Cray time to complete. The simulations were carried out for 9.0 ms of real time. The projectile exits the muzzle at 7.2 ms. The pressure drops to zero immediately as the projectile leaves the tube, and the simulation continues to 9.0 ms to determine near-exit parameters.

Some of the postprocessing was performed with BLOT [9]. The code reads output from PRONTO3D and produces contour, space, or time plots for the user. This code was primarily used for the contour plots and displaced geometry plots in this study. To determine differences from each run, completed plot dumps were created, animated, and output onto video tape. Animation proved helpful in determining relative effects from the 13 runs completed for the study. Displaced shapes were also extracted using the BLOT program. From time history plots of displacement at axial locations along the rod, fits of the data were calculated. Software produced inhouse determined rod pitch, yaw, pitch rate, and yaw rate at five temporal locations inbore and two temporal locations after leaving the muzzle.

The matrix of simulations is shown in Table 1. The 13 runs completed for the study included 8 simulations in launch tube SN81 and 5 simulations in launch tube SN104. The matrix of simulations was chosen to determine the effect of launch environment, symmetric base pressure versus asymmetric performance, duration of asymmetry, and initial position.

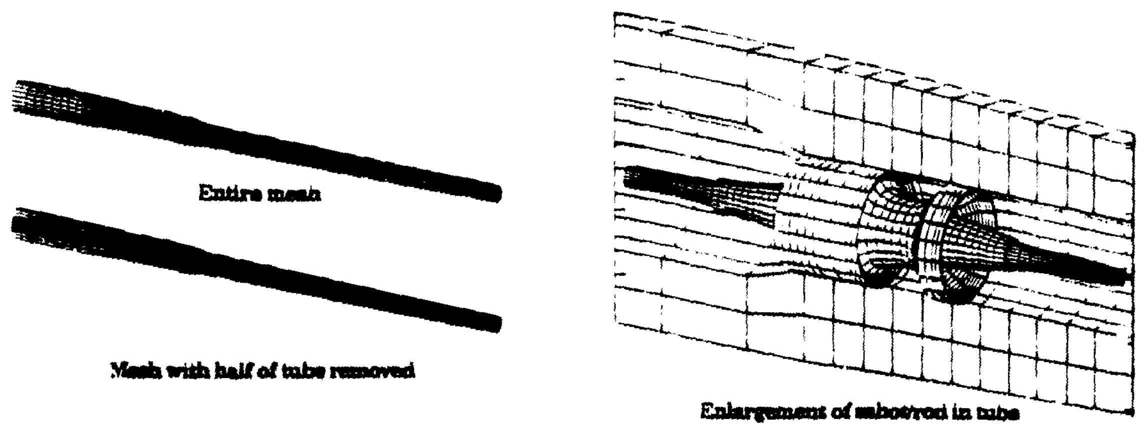

Fig. 3. Components of finite element mesh.

TABLE 1. SIMULATIONS PERFORMED

Launch Tube Environment	Symmetric Pressure vs Asymmetric	Initial Projectile Tilt (deg)	Asymmetry Transition to Symmetric (ms)	Direction of Asymmetry
SN81	Symmetric	0	-	-
SN81	Asymmetric	0	3.9	up
SN81	Asymmetric	0	3.9	down
SN81	Asymmetric	0	3.9	left
SN81	Asymmetric	0	3.9	right
SN81	Asymmetric	0	2.65	up
SN81	Asymmetric	0	2.65	down
SN81	Symmetric	0.15 up	-	-
SN104	Symmetric	0	-	-
SN104	Asymmetric	0	3.9	up
SN104	Asymmetric	0	3.9	down
SN104	Asymmetric	0	3.9	left
SN104	Asymmetric	0	3.9	right

Numerical Simulations for Gun Tube SN81- Eight simulations were performed using the SN81 tube profile. Launch tube SN81 represents a severe lateral load environment. It is not representative of launch tubes that are currently being fielded, but it provides a profile that exerts a severe path change on the projectile at a known location. After approximately 3810 mm of travel while traveling at a speed of approximately 1575 m/s, the projectile is forced through a bend in the tube. The eight simulations performed represent variations in pressure loading from the symmetric pressure case to four separate orientations of pressure asymmetry with the pressure asymmetry converging to symmetry at two separate times. One of the symmetric pressure runs included an initial tilt of 0.15 deg for the projectile at time zero.

Figures 4 and 5 show the displaced shape of the projectile for the symmetric loading, the tilted up projectile, the pressure up, the pressure down, the pressure left, and the pressure right simulations at 3.75 and 7.50 ms. In all of the asymmetric pressure cases, the asymmetry reverts to symmetry at 3.9 ms. This time represents peak base pressure. The projectile leaves the muzzle at 7.2 ms. The collage of shapes from the six simulations are presented to compare the projectile shape at the times listed.

At 3.75 ms (Fig. 4) the base pressure has increased to 315 MPa. The 2% pressure asymmetry represents 6.3 MPa at this time. The projectile has moved 447 mm and is traveling at 585 m/s. The projectile continues to displace in the direction of loading without bending the forward portion of the rod. The projectile still has not encountered deviations in tube straightness.

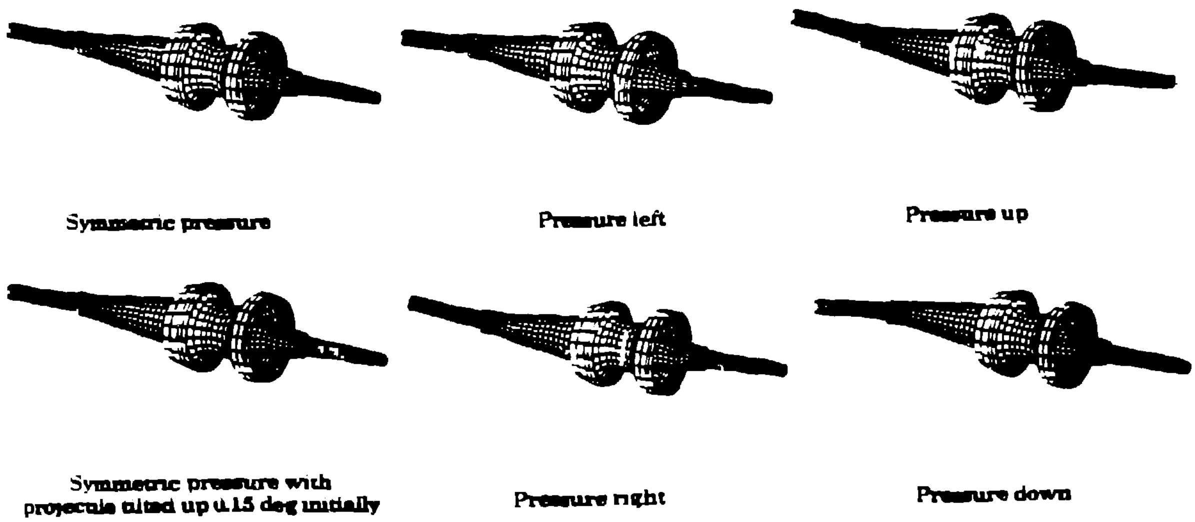

Fig. 4. Projectile displaced shape at t=3.75 ms for SN81 symmetric and tilted up symmetric simulations with asymmetry ending at 3.9 ms (magnification factor = 10).

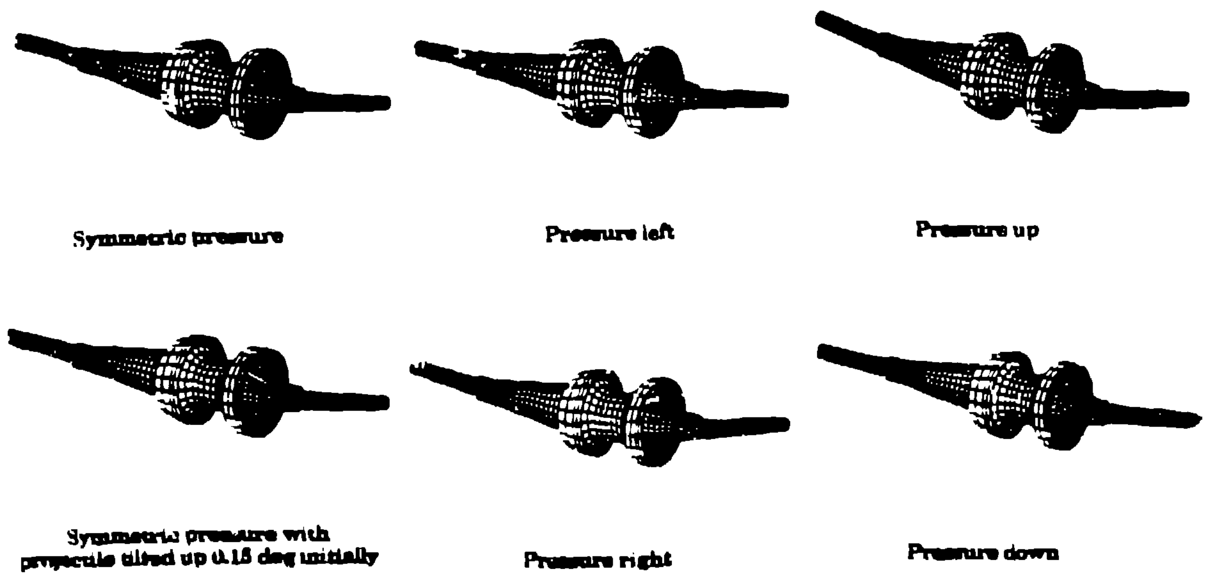

Fig. 5. Projectile displaced shape at t=7.50 ms for SN81 symmetric and tilted up symmetric simulations with asymmetry ending at 3.9 ms (magnification factor = 10).

At 7.5 ms (Fig. 5) the projectile has left the gun tube (it exits the tube at 7.2 ms), traveling 1662 m/s. Its base pressure is dropped to zero at muzzle exit. It has encountered all of the launch tube deviations and is now flying free. The displaced rods from the symmetric pressure case and the tilted-up symmetric pressure case have similar shapes. The pressure-up simulation has the most severely distorted shape. At 7.5 ms the effects of the asymmetry and tube profile are combined for the pressure-up condition, and decreased for the pressure-down condition.

The simulations performed in SN81 show that the rods are only slightly affected at early times until pressure builds closer to the peak base pressure. The displaced shapes differed dramatically by varying the asymmetry-to-symmetry transition time. Late in the projectile inbore flight, the tube profile dominated the projectile's displaced shape because of the dramatic lateral accelerations encountered in the gun at late time.

Displaced shapes of the projectile were compared at several times for simulations using tube SN81. Additional data were extracted to determine pitch, yaw, pitch rate, and yaw rate at the same temporal locations. Figure 6 shows a gun tube profile exaggerated at time 0.00. For the simulations the XYZ coordinate system shown at the breech was used. This coordinate system represents the initial orientation of the projectile. The positive X-direction is to the left, looking down on the gun tube. The positive Y-direction is up and positive Z-direction is along the initial tube direction. As discussed previously, each gun tube droops and has a distinct tube profile. The pointing angle of the gun is different from the XYZ coordinate system and is represented with a new coordinate system designated X'Y'Z'. In this case the Z'-direction is along the initial pointing angle of the muzzle of the gun. Data were extracted and processed at 7 temporal locations (1.50, 2.25, 3.00, 3.75, 4.50, 7.50, and 9.00 ms). Left is in the positive X' direction (Fig. 6). Lateral velocity of the projectile is provided between the 7.5 and 9.0 ms times for both the X'Z' and Y'Z' planes.

Figure 7 shows pitch versus time for the eight simulations performed using tube SN81. The top-right graph compares the symmetric pressure case, the up and down asymmetric cases with asymmetry reverting to symmetry at 3.9 ms; and the symmetric tilted-up initial-condition case. The symmetric case indicated by the circles, shows little pitch during the first 4.5 ms of flight. After the projectile exits the gun, the tube profile predicts that the penetrator will be pitched down at both 7.5 and 9.0 ms. The asymmetric pressure-up case is shown by the square data points. In this case the upward pressure on the aft of the projectile causes downward rotation until the projectile forward bell contacts and gun tube, flexes, and then rebounds near the 4 ms mark. The projectile exits with a completely different pitch, with the projectile pointing up at both the 7.5- and the 9.00-ms marks. During the first 4.5 ms, almost identical behavior is seen for the initially tilted-up case. Exit parameters are larger in magnitude, and the projectile is pitched down at both 7.5 and 9.0 ms.

In the bottom graph of Fig. 7, the symmetric pressure case is plotted again for reference, with the up and down asymmetry cases reverting at 2.65 ms. The trends are similar to the previous plot during the first 4.5 ms, but the magnitude and response times have decreased. The third graph shows the pitch versus time for the right and left asymmetric pressure cases reverting at 3.9 ms. The pitch response during early time is essentially zero. After the projectile travels through tube SN81, the projectile response is varied between the three simulations.

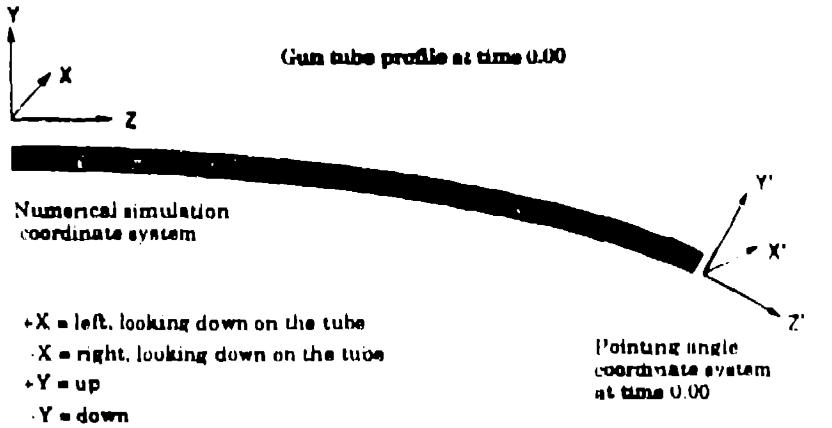

Fig. 6. Simulation and pointing angle coordinate systems.

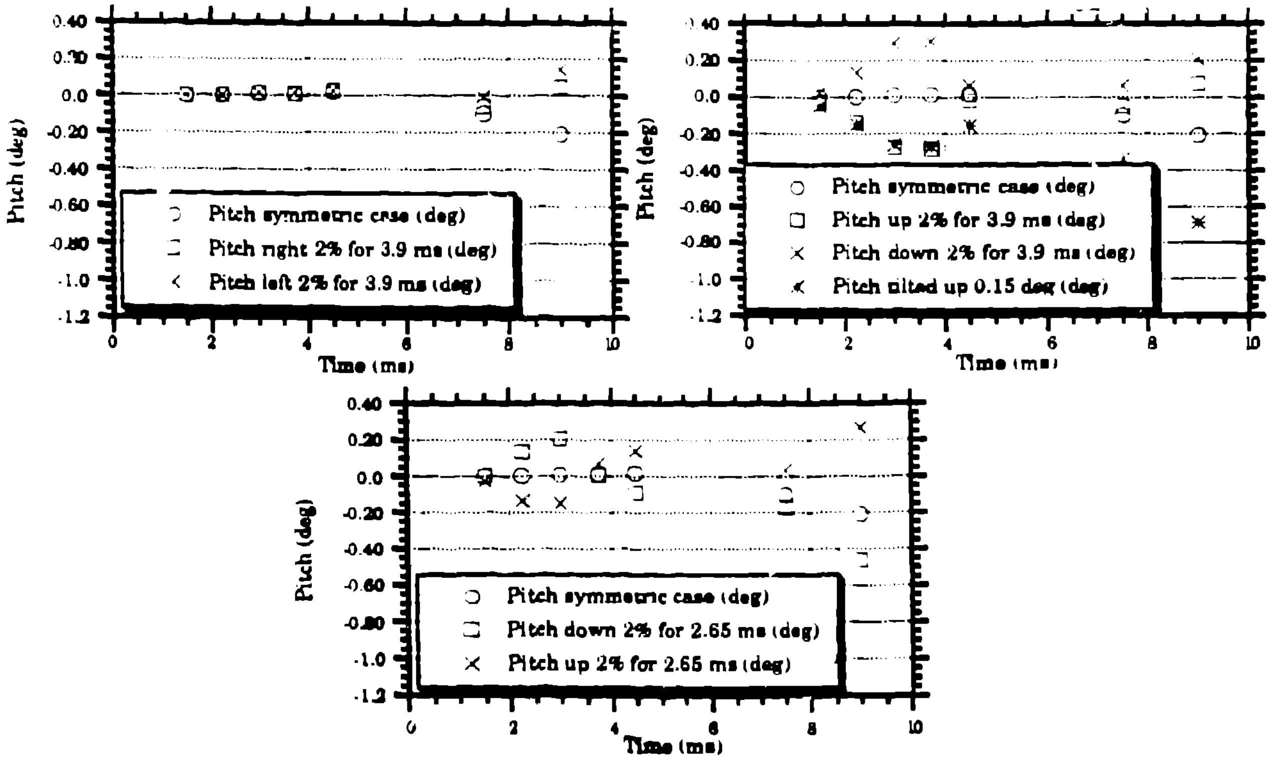

Fig. 7. Pitch versus time for simulations using launch tube SN81.

SUMMARY

Thirteen three-dimensional simulations were performed to study the effects of pressure asymmetry during projectile launch. Eight simulations were completed using the SN81 tube profile and configurations. These simulations include the symmetric base pressure case and the asymmetric pressure cases, with 2% pressure deviations across the sabot aft ramp and rod in the up, down, left, and right configurations where the asymmetry reverts to symmetry after 3.9 ms. Two additional asymmetric cases investigated the asymmetric pressure reverting to symmetric base pressure at 2.65 ms. The last simulation using the SN81 profile, had symmetric base pressure, but the projectile was initially tilted up 0.15 deg in the gun. Five simulations were completed using the SN104 tube profile. These simulations included the symmetric pressure case and asymmetric cases reverting at 3.9 ms in the up, down, left, and right orientations.

Displaced shapes were output and compared for the thirteen simulations. Pitch, yaw, pitch rate, and yaw rate were extracted from the nodal data and presented in tabular and graphical form to compare the differences between the simulations. Animations of the simulations were created to compare the projectile shapes, while inbore, for all of the simulations. Some of the highlights from the simulations are listed below.

- Limited data were available on the magnitude, duration, and orientation of pressure asymmetry. A 2% variation was used across the projectile with durations of 2.65 and 3.9 ms.
- While the pressure asymmetry is applied, the projectile does not encounter any tube straightness deviations. For the 3.9-ms case, the asymmetry reverts to symmetry after the projectile has traveled about 19.0 in. Tube deviations in straightness occur after 24 in. of travel, when the base pressure is ramping down from peak pressure.

- Response to the base asymmetry was consistent with the direction of the pressure asymmetry. In all cases the projectile rotates until the forward bell impacts the tube wall, flexes, and then bounces back. The magnitude of the flexure was dependent on the duration and the magnitude of load.
- After the asymmetry was reverted to symmetric base pressure, the projectile was then influenced by tube profile and by the inertial loads of the vibrating projectile.
- The influence of pressure asymmetry remains with the projectile after muzzle exit. If the phase of projectile response caused by the pressure asymmetry is in or nearly in phase with the forcing function, the magnitude of displacement is increased, as indicated in both up-pressure asymmetric cases.
- The exit parameters were influenced by the early base pressure and by the projectile's initial position. The near muzzle exit results are affected by a combination of pressure asymmetry, duration, and tube profile location with the current projectile displaced shape.
- Asymmetric base pressure influences the inbore behavior and the near muzzle exit parameters. It is not eliminated by the more dominant tube straightness parameters at late time.

The work indicates that the pressure asymmetry may be a source of projectile motion within the gun tube and may contribute to dispersion at the target. Future work should be undertaken to determine the magnitude and cause of any asymmetric base pressure and its orientation and duration. That work would provide data that would determine the effect of the asymmetry on projectiles while inbore. Characterizing the three-dimensional environment of pressure within the chamber is a major experimental undertaking. Insights could possibly be gained in scaled experiments and in three-dimensional simulations of propellant bed combustion and compaction.

Acknowledgments- This work was funded by the Office of Program Management - Tank Main Armament Systems (OPM-TMAS) and the U.S. Army Ballistic Research Laboratory (BRL) under the direction of W. Lang. B. Burns and B. Kaste provided the data required for the simulations and were the technical points of contact within the Army. R. B. Parker and W. D. Birchler helped with the coordinate system transformation and wrote the postprocessing software for the flight analysis. The authors wish to thank these individuals for their help in this work.

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