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BANDSLIP Advancements

by Michael Minnicino

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14. ABSTRACT

A munition is said to be despun when the munition's angular velocity is significantly less than its band's angular velocity, thus the band slips on the munition and, hence, the name "slipband." With the emergence of smart munitions that possess advanced guidance for dynamic targeting capabilities, despun munitions are seen as the best approach for survivability of these fin-stabilized, canard-guided munitions due to the reduced aerodynamic loads on the fins and canards. The BANDSLIP code used for predicting the spin history of munitions has been improved. The most notable improvement is the capability to simulate projectiles shot through progressive twist gun tubes.

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1. Introduction

The original BANDSLIP R1.0 was developed by Sandia National Laboratory (Livermore, CA) as a computational tool used to predict the dynamic behavior of despun munitions.[1] BANDSLIP R1.0 was distributed to the U.S. Ballistics Research Laboratory in 1989 and was later successfully used to qualitatively predict the dynamic behavior of a 105-mm despun munition using different slipband designs.[2] This code was incrementally modified until it was unified as BANDSLIP R1.2.[3] A detailed explanation of the code can be found in Minnicino.[3] Recent modifications of the BANDSLIP R1.2 code are described herein. This new version of the code is referred to as BANDSLIP 2.0.

2. Theory

A munition is said to be despun when the munition's angular velocity is significantly less than the obturation band's angular velocity, thus the band slips on the munition and, hence, the name "slipband." With the emergence of smart munitions that possess advanced guidance for dynamic targeting capabilities, despun munitions are seen as the best approach for survivability of these fin-stabilized, canard-guided munitions due to the reduced aerodynamic loads on the fins and canards.

The cross section of a typical slipband design is shown in figure 1. From this figure, it is seen that the slipband rides on a section of material denoted as the bandseat, which is outlined in the figure by dashed lines. From experience, it is recommended that the slipband ride on a polymer bandseat for performance and reliability.[2] The polymer bandseat is permanently fixed to the subprojectile. Therefore, the bandseat rigid body dynamics, i.e., linear and angular displacements, linear and angular velocities, and linear and angular accelerations, are equivalent to the subprojectile's rigid body dynamics. A design utilizing a distinct bandseat material relative to the slipband and the subprojectile is referred to as a two-piece slipband design. Conversely, if the bandseat is provided by the subprojectile material, it is referred to as a one-piece slipband design. The base pressure is the pressure acting normal to the munition's surfaces rear of the band due to the propellant deflagration. The tube pressure is realized after the slipband is radially compressed by passing through the gun's forcing cone and subsequently

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[1] Nielan, P. E. Spin Rate Prediction for Projectiles with Slipping Obturators; presentation handout, U.S. Army Ballistics Research Laboratory: Aberdeen Proving Ground, MD, 7 September 1988.

[2] Kaste, R. P. *Development of a Design Methodology for Slipband Obturators*; BRL-TR-3297; U.S. Army Ballistics Research Laboratory: Aberdeen Proving Ground, MD, 22 November 1991.

[3] Minnicino, M. A. *BANDSLIP R1.2 Theory and User's Guide*; ARL-TR-3598; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, September 2005.

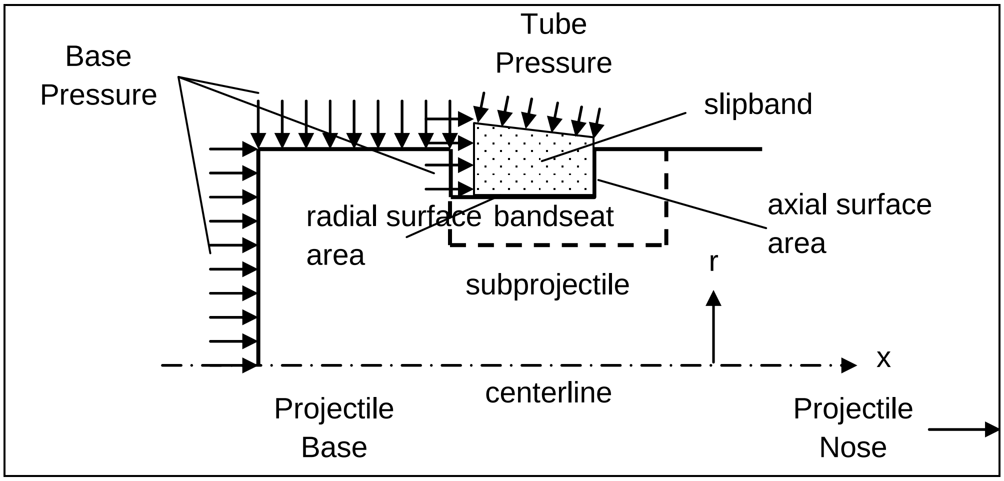

Figure 1. Illustration of a typical two-piece band cross section.

remains radially confined by the gun tube's inner wall. The effect of the tube pressure provides a compressive radial stress between the slipband and the bandseat. The magnitude of the induced radial stress is difficult to determine and is not constant along its length (x-direction) but can be adequately estimated through a Lamé stress analyses.

There are two processes that decouple the projectile from the gun tube's rifling. The first is melting the interface between the bandseat and slipband. The second is reducing torque transfer capability between the bandseat and slipband by the base pressure. These two processes are explained next.

The BANDSLIP code calculates the torque required to spin the projectile at the same rate as the kinematically constrained slipband. The code also calculates the maximum torque that can be transmitted from the slipband to the bandseat/subprojectile. When the maximum transmittable torque is less than the required torque, the slipband "slips," i.e., it spins relative to the bandseat. Heating of the bandseat-slipband interface is generated by this relative motion through frictional heating and is proportional to the coefficient of friction between these two surfaces and the difference in rotational velocity. The amount of heating is significant enough to melt either one or both of the bandseat or slipband materials, resulting in a liquid interface that is unable to transmit torque. (See Minnicino[3] for a more detailed explanation of the heating analysis.)

The base pressure acts to negate the tube pressure. Hydrostatics dictates that when the magnitude of the base pressure becomes larger than the effective tube pressure, the normal traction between the bandseat and slipband on the radial surface is 0. No torque can be transmitted across the radial surface when the normal traction is 0. This condition is termed "lift-off" as the slipband is lifted from the bandseat by the base pressure. The axial surface becomes the only surface able to transfer torque from the slipband to the bandseat under this condition. Additionally, it should be noted that the slipband still provides obturation since there is still a gas-tight seal at the bandseat-slipband axial surface interface. The munition's angular velocity is therefore limited to its angular velocity when axial and radial surfaces have melted or the radial surface has lifted and the axial surface has melted.

3. Simulation of Projectile Spin History With Progressive Twist Rate Gun Tubes

A general formulation of the slipband's dynamic quantities is now developed. Recall that the slipband's linear dynamic quantities are equivalent to the bandseat/projectile and its angular dynamic quantities are kinematically constrained by the rifling. A gun tube's rifling profile is expressed in terms of circumscribed arc length of the lands and grooves in a plane normal to the tube's centerline, as shown in figure 2a. The result of this rifling profile representation for a constant twist gun tube is a straight line, as shown in figure 2b, where the x-s coordinate system is 0 at the origin of rifling and twist is defined as the revolutions per caliber of travel. Certain guns, such as the M119, have a progressive or gain-twist rifling profile where the twist at the origin of rifling is less than the twist at the muzzle. Further, the rifling profile need not be linear. For example, the rifling profile for the M119 gun tube is quadratic and can be expressed generally as follows:

$$s(x) = c_1 x^2 + c_2 x + c_3 \ . \tag{1}$$

However, the arc length is equivalently

$$s = r\theta \ . \tag{2}$$

Defining the gun rifling as a function of the independent spatial variable, x, in equation 1 and using the arc length-rotation relation given in equation 2 allow simple differentiation of the rotational velocity and acceleration as follows:

$$\theta = \frac{s(x)}{r} \ , \tag{3}$$

$$\dot{\theta} = \frac{d}{dt}\left[\frac{s(x)}{r}\right] = \frac{1}{r}\frac{ds}{dx}\dot{x} \ , \tag{4}$$

and

$$\ddot{\theta} = \frac{d}{dt}\left[\frac{1}{r}\frac{ds}{dx}\dot{x}\right] = \frac{1}{r}\frac{d^2 s}{dx^2}(\dot{x})^2 + \frac{1}{r}\frac{ds}{dx}\ddot{x} \ , \tag{5}$$

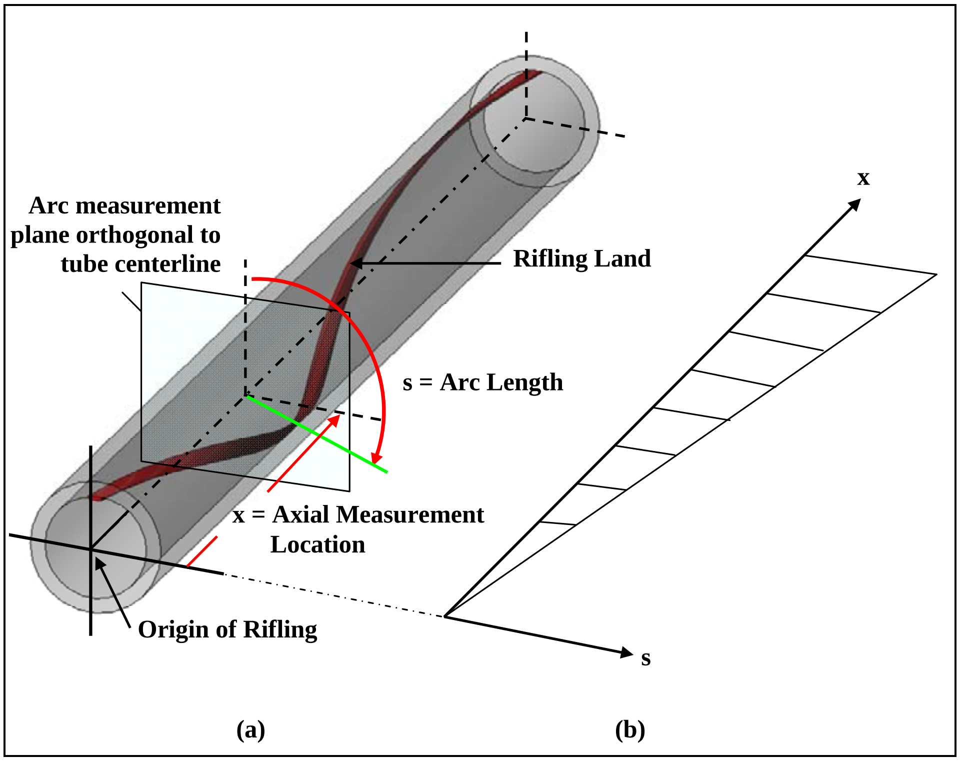

Figure 2. Section of a gun tube showing a single rifling land to illustrate (a) the measurement system used to define a gun tube's (b) rifling profile.

where *s(x)* is the prescribed rifling profile, $\dot{x}$ is the projectile's linear velocity, $\ddot{x}$ is the projectile linear acceleration, and *r* is the tube radius. Applying Newton's second law gives

$$\ddot{x} = \frac{PA}{m} \ , \tag{6}$$

where *P* is the base pressure, *A* is area the base pressure acts on, and *m* is the projectile mass.

Once the linear acceleration is computed for the current time step, the linear velocity and displacement are calculated using finite-difference methods. Subsequently, the angular acceleration for the current time step is computed using equation 3. The slipband's angular velocity and displacement are calculated using finite-difference methods. However, the bandseat's/projectile's angular quantities are determined by a more complicated algorithm discussed in Minnicino.[3]

4. Case Study

In this section, the BANDSLIP software is a-posteriori compared with the 105-mm artillery very affordable precision projectile (VAPP) slipband demonstration data. The VAPP uses a two-piece slipband design and is shot through an M119 gun, which uses a progressive twist gun tube. The input to the BANDSLIP software includes the two-piece band geometry and material properties, the projectile's inertial properties, and a filtered base pressure-time history. Additionally, the compressive radial prestress between the slipband and bandseat is estimated to be 9.43 ksi (65 MPa) through a Lamé analysis. The coefficient of friction between the slipband and the bandseat is assumed to be 0.10.

To illustrate the utility of the BANDSLIP software and provide evidence that the updated code correctly accounts for progressive twist gun, the results for an M67 zone 3 VAPP shot are presented. A filtered base pressure-time history for an M67 zone 3 VAPP shot is used, as shown in figure 3. The linear acceleration, shown in figure 4, is simply the base-pressure time history linearly scaled per equation 6. It should be noted that the linear dynamic quantities are the same for the slipband and the bandseat/projectile since they are physically constrained. The BANDSLIP computed linear velocity and displacement time histories are shown in figure 5. The experimental muzzle velocity for this shot is 231 m/s, and the travel distance for the M119 is 2.70 m. BANDSLIP predicts the muzzle velocity as 230 m/s, and the travel distance is 2.68 m.

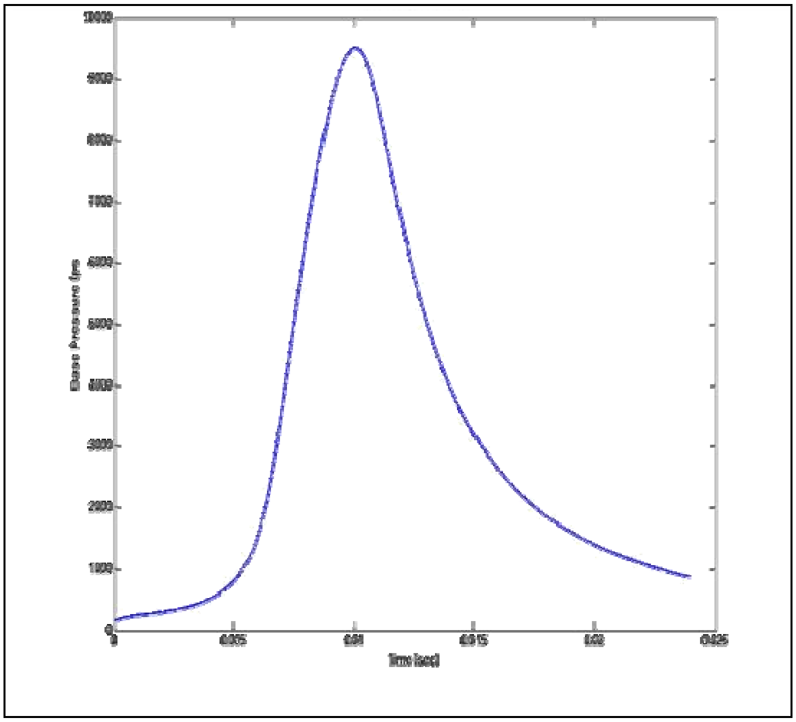

Figure 3. M67 zone 3 filtered base-pressure time curve.

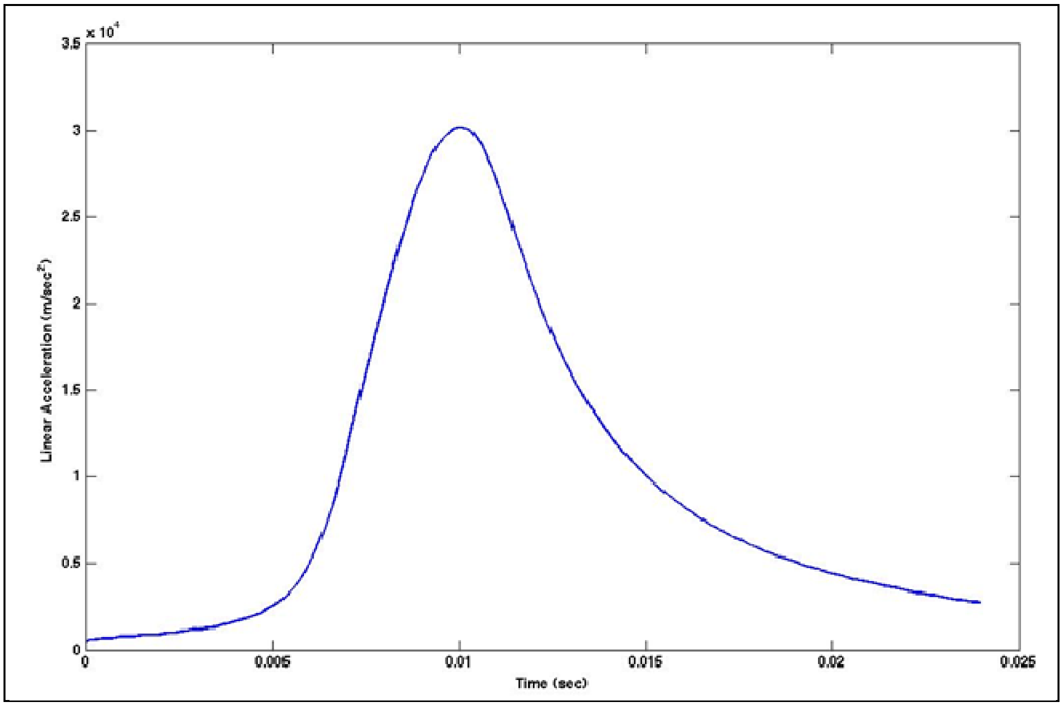

Figure 4. Linear acceleration time history.

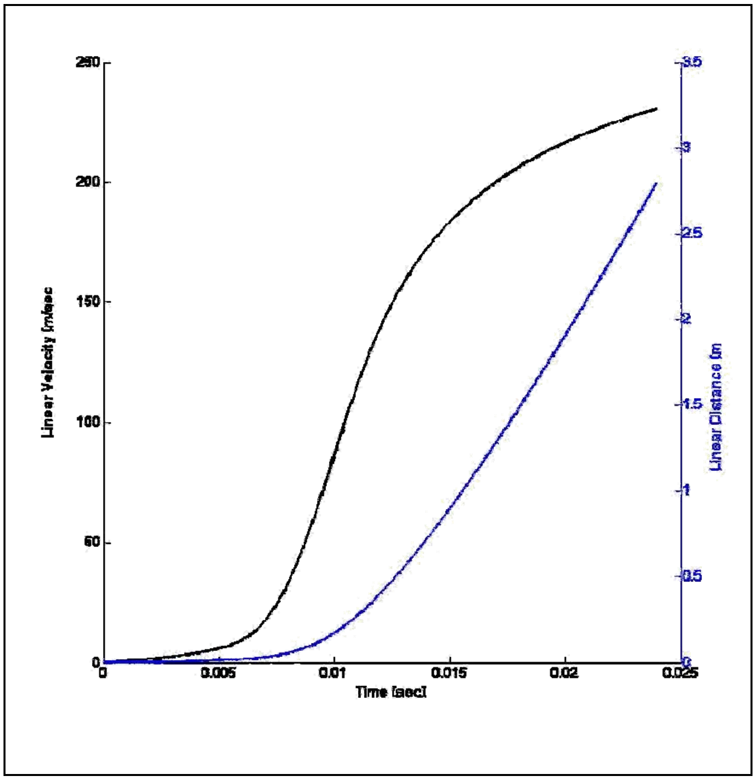

Figure 5. Linear velocity and displacement time histories.

The angular acceleration of the slipband is shown in figure 6. Compared to a constant twist rate gun tube, the angular acceleration does not decay in the same manner as the linear acceleration. However, since VAPP is shot through a progressive twist gun tube, the angular acceleration remains large, even as the linear acceleration significantly decreases.

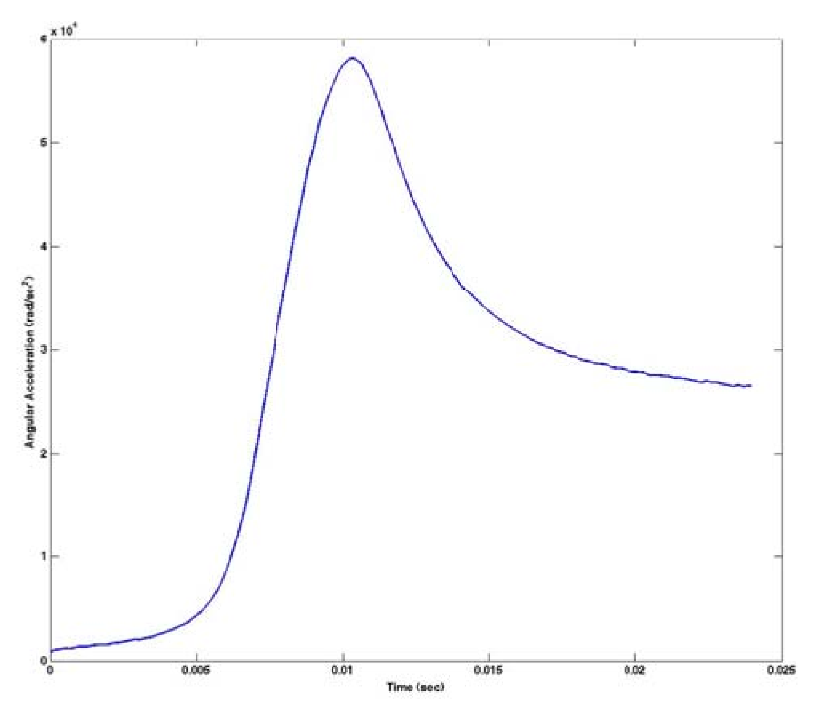

Figure 6. Slipband angular acceleration time history.

The angular velocity of the slipband and the bandseat is shown in figure 7. The bandseat's angular velocity is the same as the slipband's angular velocity until slipping begins. At that time, the bandseat's angular velocity increases at a slower rate than the slipband. Figure 8 highlights the data from 8 to 11 ms in figure 7. In this figure, the angular velocities of the bandseat are less than the slipband beginning at ~8.5 ms. The rate of divergence in angular velocity is small near this time. The slip is from the torque's capability of being transferred from the slipband to the bandseat; projectile assembly is less than required. At 9.75 ms, the rate of divergence increases significantly because the slipband lifts from the bandseat by the base pressure. Recall that a compressive radial prestress of 9.43 ksi (65 MPa) is prescribed between the slipband and bandseat; the base pressure at 9.75 ms is ~9.43 ksi (65 MPa). Therefore, once the compressive radial prestress has been overcome, only the axial interface can transmit torque and at a much lesser extent. The large difference in angular velocities produces more frictional heating that, if given enough time, can cause the axial face to melt and thereby cease the torque transmission. At the moment when torque can no longer be transferred, the bandseat/projectile's angular velocity obtains its final value, as represented by the flat slope of the bandseat's angular velocity.

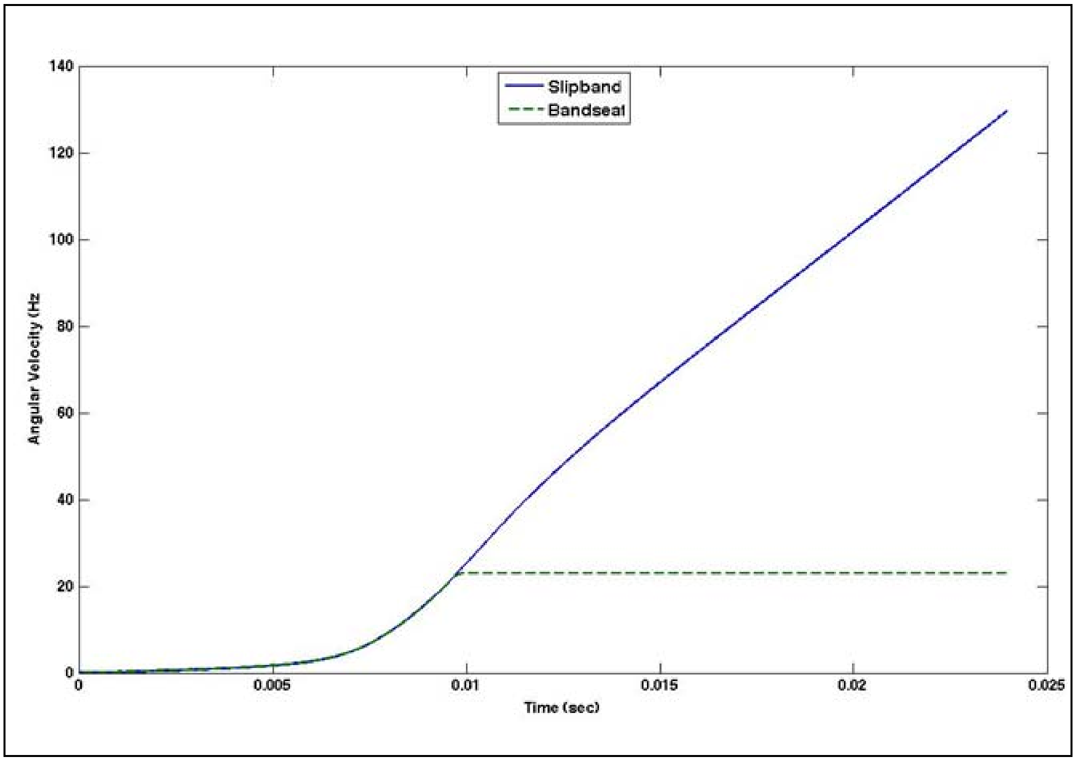

Figure 7. Comparison of slipband and bandseat angular velocity time histories.

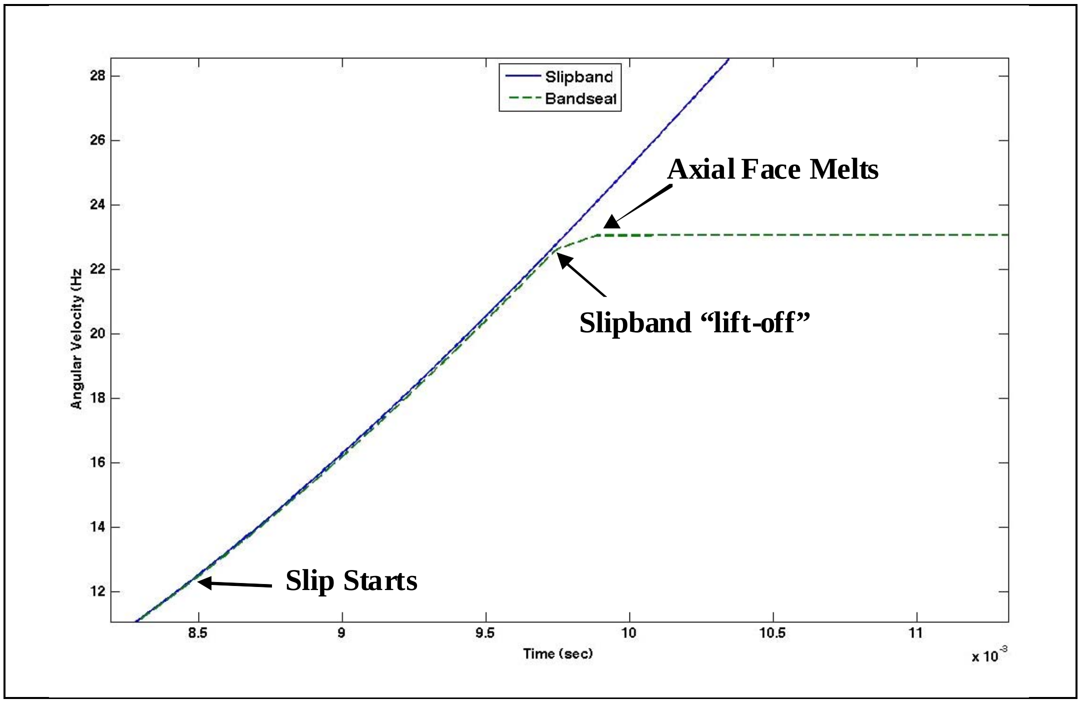

Figure 8. Comparison of slipband and bandseat angular velocity time histories during the period of relative motion.

A comparison between the experimental and BANDSLIP-predicted projectile angular velocities at muzzle exit is shown in figure 9. It is seen that for low propelling charge masses, BANDSLIP overpredicts the muzzle angular velocity. Conversely, it is seen that BANDSLIP underpredicts the angular velocity at larger propelling charge masses. BANDSLIP provides insight into two-piece band designs but not quantifiable numbers.

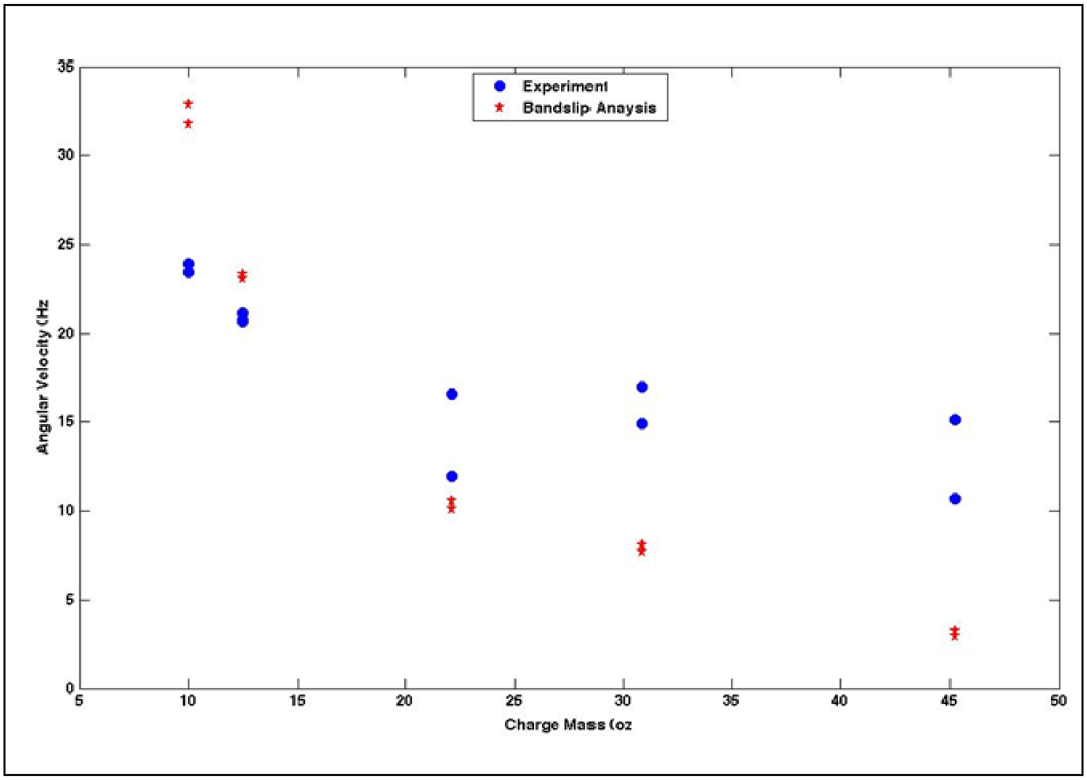

Figure 9. Comparison of experimental and BANDSLIP 2.0 predicted projectile muzzle angular velocities for various propelling charge masses.

The lack of quantitative results can be attributed to uncertainties of interface stress and coefficient of friction between the slipband and bandseat materials. The slipband material is nylon. Depending on formulation and manufacturing process, the thermomechanical material properties of nylon vary immensely. Typical commercial-grade values were chosen for the BANDSLIP analysis. Additionally, viscoelastic effects of the slipband and bandseat materials were not considered in the BANDSLIP software, therefore, possibly adding to lack of quantitative results.

5. Summary

BANDSLIP R1.2 has successfully been updated and can simulate despun projectiles shot through progressive twist rate gun tubes. This updated version of the code is denoted as BANDSLIP R2.0. The method in which rifling profiles are defined is explained. Lastly, the derivation of the equations used to simulate progressive twist rate gun tubes using a general rifling profile has been documented.

BANDSLIP predictions may be improved by more comprehensive testing of the slipband and bandseat materials in order to accurately determine their thermomechanical elastic properties and significance of viscous effects. Additionally, the thermomechanical material properties can be used in a three-dimensional, finite-element analysis to provide a more detailed interface stress between the slipband and bandseat as they pass through the forcing cone and engrave on the rifling.

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