Use of Yaw Cards During Projectile Development

Virtually every projectile leaving the muzzle of a firearm has some initial launch disturbance upon emergence from the bore, causing it to fly with a non-steady angle of attack, as shown in Figure 1. A single witness card placed in front of the gun muzzle would show a non-circular hole in the paper, indicating the projectile, at that instant, is flying with an angle of attack.

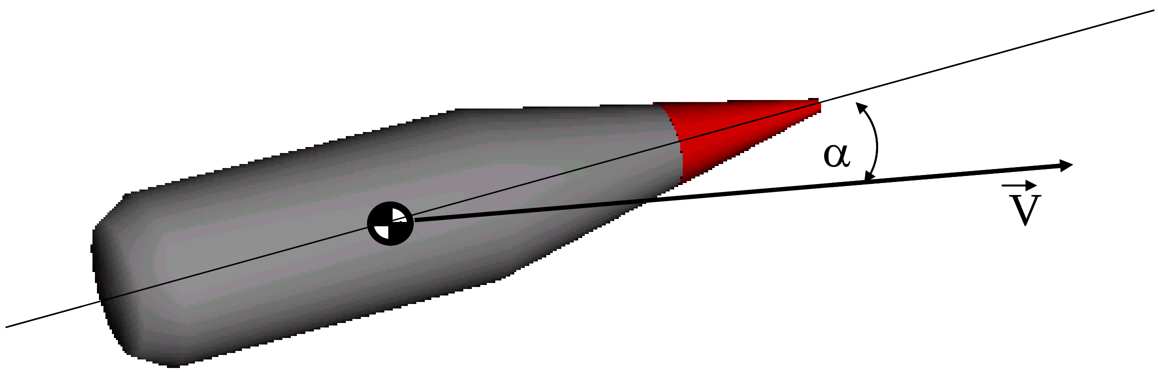

Figure 1: Projectile Angle of Attack with respect to Velocity Vector

A series of witness cards, commonly called "Yaw Cards", placed in the flight path can yield a surprising amount of information about the projectile aerodynamics simply by collecting a few bits of data at each card. This test and subsequent analysis can be conducted for a fraction of the cost of other commonly used methods to acquire aerodynamic data. A few wood pallets, some 2x4's, some nails, some large rolls of waxed butcher paper, and a staple gun are all you need to get started collecting real aerodynamic data.

What Are Yaw Cards?

Yaw cards are a series of low density targets nailed, stapled or taped to a light weight frame through which a projectile flies; shown in schematic form in Figure 2.

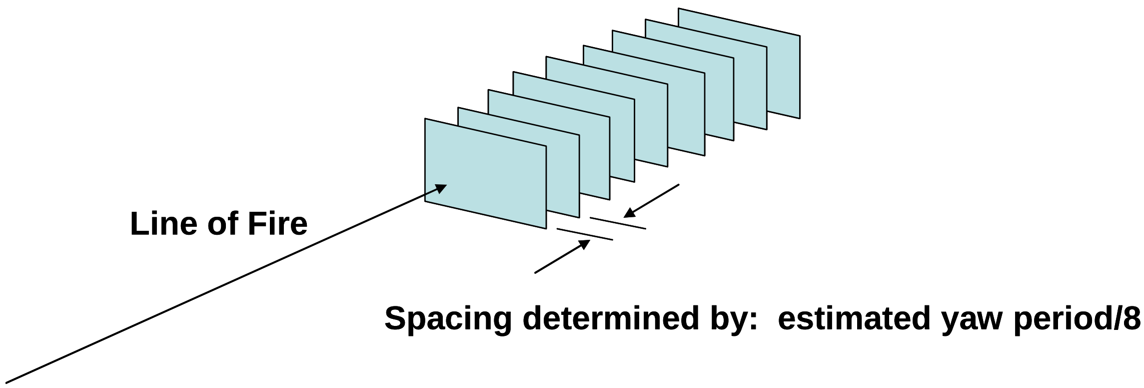

Figure 2: Typical Yaw Card Setup

Since every projectile has some initial launch disturbance when emerging from the muzzle, the imprint left by the projectile passage through the yaw cards is non-circular, to some degree.

When firing in an indoor range, the yaw cards can be made from very low strength material, which helps to minimize the disturbance to the projectile imparted by the yaw cards. When firing outdoors, the user must balance the need for the yaw cards to survive any winds which may arise during testing with the need to impart minimal disturbance to the projectile. Typically, the smaller the caliber projectile, the lower density and lower strength the yaw cards need to be to avoid influencing the results.

In some instances, and especially with small caliber projectiles, the initial yaw rate at muzzle exit may need to be amplified to make the projectile angle of attack visible in yaw cards. This can be accomplished by temporarily attaching a simple device to the muzzle of the gun to make the muzzle blast dramatically asymmetric. This imparts an unbalanced load to the projectile, inducing yaw relative to the projectile velocity vector. A typical muzzle device used to impart an asymmetric disturbance to the projectile to induce yaw is shown in Figure 3. It is milled from simple steel turnings, attaches temporarily to the muzzle via set screws or cap screws, and the length of the asymmetric portion can be adjusted to vary the impulse delivered to the projectile.

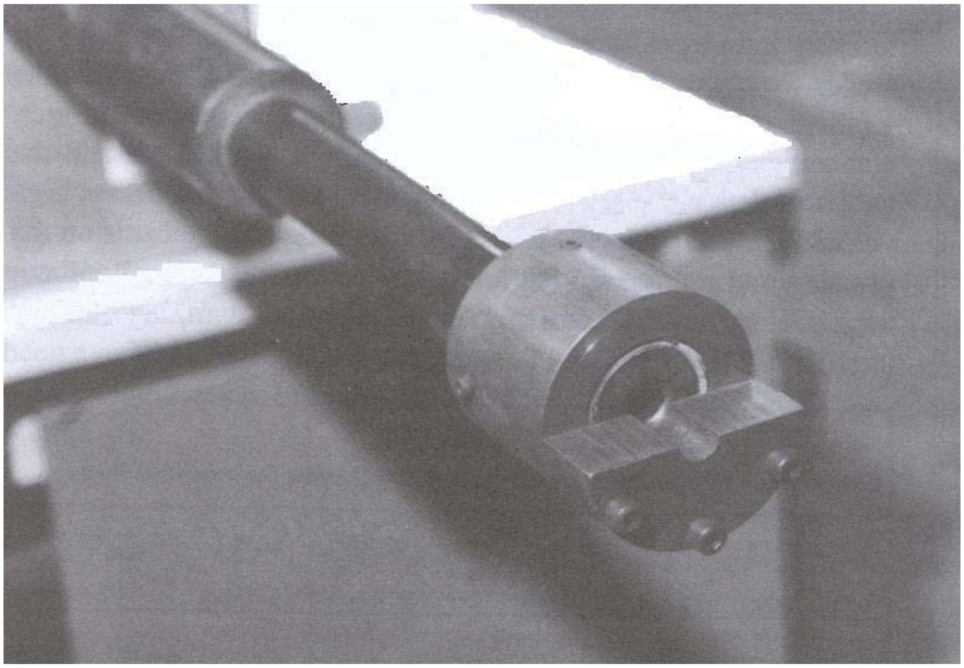

Figure 3: Yaw Inducing Muzzle Device

Why Conduct a Yaw Card Analysis?

While predictive codes do a reasonably good job estimating aerodynamic coefficients of projectiles, there are some projectile shapes and Mach regimes for which little data exists, hence prediction errors are large. In these instances, the use of yaw cards during projectile development provide measurements of key aerodynamic stability coefficients that are otherwise only available through more sophisticated and expensive measurement techniques such as wind tunnel, spark range, or yaw sonde testing. Determination of aerodynamic coefficients is especially critical when prediction errors are large, especially when the ammunition developer is attempting to reduce the dispersion sensitivity of a projectile. Yaw cards can provide information on the aerodynamic coefficients and parameters listed in Table 1, along with the projectile behavior affected by each coefficient.

Coefficient/Parameter	Affects
Pitching Moment Coeff. Derivative	Static or Gyro Stability, Dispersion
Pitch Damping Moment Coeff.	Dynamic Stability
Magnus/Side Moment Coeff.	Dynamic Stability
Roll / Roll Decay Moment Coeff. (Finners)	Steady State Roll Rate
Exit Spin Rate	Stability, Dispersion
Location of Initial Yaw Rate Source	Dispersion Troubleshooting

Table 1: Aerodynamic Coefficients which can be determined by Yaw Cards

Additionally, by extrapolating the projectile yaw motion back to the gun muzzle, the user can determine if the primary source of naturally occurring yaw disturbances (without the muzzle amplification) are from in bore sources (e.g. in-bore clearances or center of gravity offset) or exterior sources such as sabot discard. When extrapolated to the gun muzzle, if the projectile yaw is zero or nearly zero, it is most likely the exit yaw rate is due to in bore effects; while if the yaw is at or near a maximum value at the gun muzzle, the source of observed projectile disturbance is outside the gun muzzle. The ability to distinguish between the dispersion sources makes yaw cards an important diagnostic tool that helps the projectile designer isolate the source of projectile dispersion, and focus design efforts accordingly.

How Do I Determine Yaw Card Location & Spacing?

For all guns, the first card should be well out of the muzzle blast zone to prevent it being shredded by the overpressure from barrel emptying. Depending on the gun caliber, operating pressures, expansion ratio, etc., the distance to the first card may vary from as little as 30 calibers to as many as 100 calibers (or more) from the muzzle.

Spacing between the cards can be determined by running a 6 degree of freedom (6 DoF) trajectory code, inputting an initial angular rate to the projectile, and examining the yaw period of the projectile in range (in feet or meters). The cards should be placed at reasonably consistent intervals, spaced to ensure coverage of a yaw minimum and a yaw maximum. We then recommend skipping a few yaw cycles and then placing another set of yaw cards to capture an additional yaw min-max cycle. The cards should be placed at known distances from the muzzle. Equal card spacing is not necessary, but you need to record the distance from the muzzle to each card.

The proper spacing of the yaw card array can provide the following information with relative ease at low cost.

- Period of yaw
- Location of maximum and minimum yaw
- Magnitude of sabot impulse
- Gyroscopic stability factor (spin stabilized projectiles)

- Damping factors
- Aerodynamic pitching moment
- Aerodynamic damping moment
- Aerodynamic Magnus moment (spin stabilized projectiles only)
- Spin Rate (both fin and spin stabilized projectiles)

The expected yawing motion of a projectile should be simulated using the PRODAS 6DOF Trajectory analysis. This simulated motion coupled with the PRODAS Stability Analysis computations provides sufficient information for the placement of the series of yaw cards.

The material of the yaw cards can be photographic print paper for medium caliber projectiles and thin cardboard for large caliber projectiles.

For Spin Stabilized projectiles:

- 6 to 8 cards for one fast cycle
- Skip one fast cycle
- 4 to 5 cards for the next fast cycle
- Skip one fast cycle
- 4 to 5 cards for the next fast cycle
- 15 to 20 cards per cycle for 1½ planar cycles

What Data Do I Collect?:

Three options are provided to analyze the Yaw Card data:

1. Fin stabilized projectiles with little or no spin (i.e. 120mm APFSDS near the muzzle)
2. Fin stabilized projectiles with moderate spin rates (i.e. 25mm and 105mm APFSDS projectiles fired with slip obturating bands in rifled barrels)
3. Spin stabilized projectiles (7.62 through 203 mm projectiles fired from rifled cannon)

When conducting a yaw card test, preparation of the yaw card array is fairly simple. A plumb or horizontal reference line should be drawn on each card. This reference line provides the basis for measuring the axis rotation angle (ϕ) phi, shown in Figure 4. This rotation angle is always measured in a clockwise direction for the projectile imprint in each yaw card. Also shown in Figure 4 is the projectile total angle of attack information required that is obtained by use of a yaw template or by measuring the length of the hole in the yaw card signature material. The user also needs to record the distance from the muzzle to each yaw card.

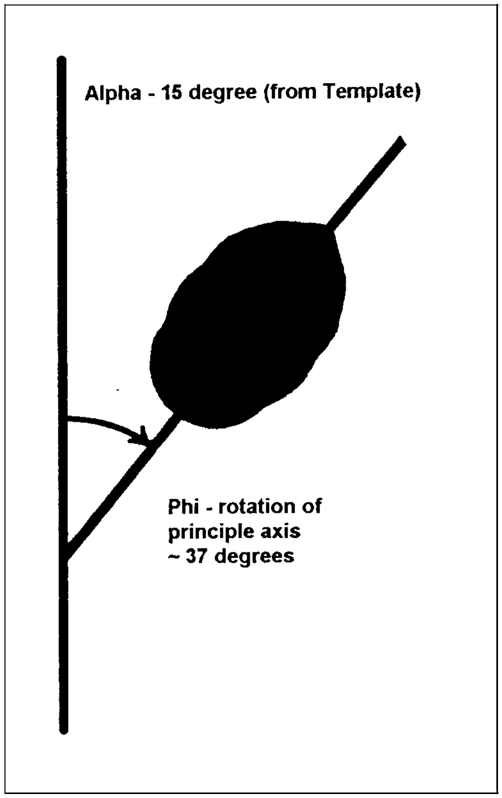

Figure 4: Yaw Card Data Example

In practice, if the expected projectile flight path is well known, the user can start a yaw card test by positioning the cards so the projectile flies through the cards near one edge of the cards, and then translate the yaw card stands after each shot 4-6 calibers in one direction perpendicular to the line of flight. This technique reduces the time required to conduct a test series by eliminating replacement and the required reference marking for each yaw card. Depending on the size of the projectile and the yaw cards, many samples can be acquired per yaw card set up.

A template can be prepared to facilitate card measurement of Total Yaw (angle of attack) and orientation of the yaw plane relative to vertical. Figure 5 illustrates a typical template. Use of a template is highly recommended, as with a little use, the imprint of the yawed projectile on the signature material that doesn't generate a hole becomes apparent to the trained eye. This allows improved estimates of the projectile yaw at each yaw card, reducing the fit errors and improving the estimates of the aerodynamic coefficients.

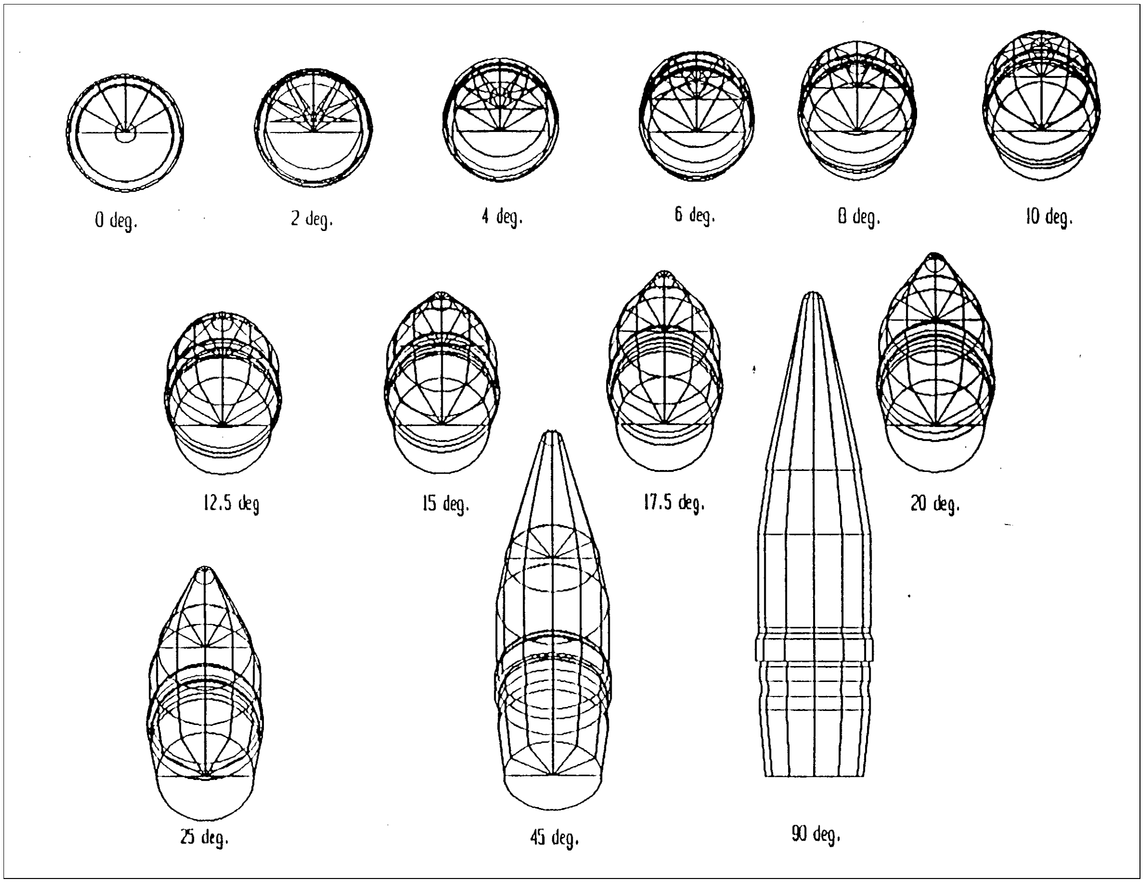

Figure 5: Yaw Card Templates

The variety of yawing motions of projectiles is illustrated by Figure 6 that was extracted from BRL Report 921. All of the motions can be modeled by Linear Theory over short distances (up to 300 m).

Reference: Zoroodny of BRL

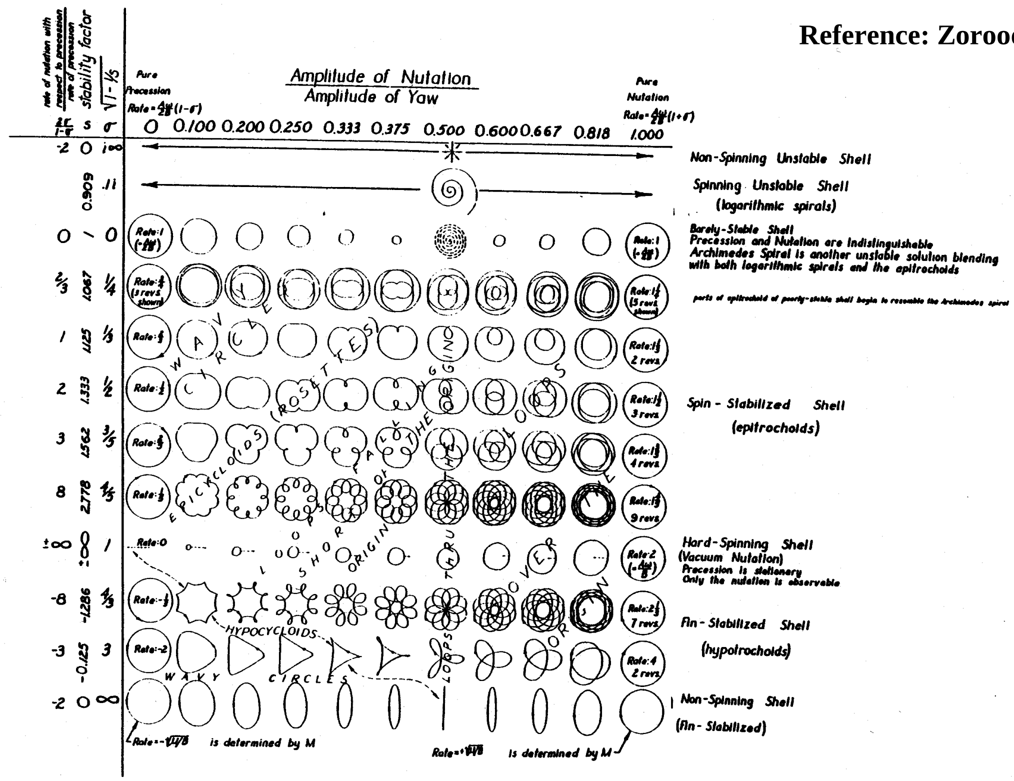

Figure 6: Projectile Yaw Motion