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ON THE INFLUENCE OF YAW AND YAW RATE (MAGNITUDE AND ORIENTATION) ON DISPERSION

W.J. Rossouw

Ballistics Research Group, Denel Ordnance, PO Box 7710, Pretoria 0001, South Africa

A yawing projectile possesses a higher retardation than a well-launched one. This leads to the yawing projectile generally ranging shorter whereby group dispersion may become unacceptable.

Less known is the fact that yawing jeopardises line dispersion as well, because it may influence projectile drift.

In this paper we use a six degree of freedom trajectory model to explain the impact of yaw and yaw rate (magnitude and orientation) on the fall of shot pattern of spin stabilised projectiles. The possibility of minimising the effect of yaw on dispersion by controlling the orientation of yaw is discussed.

A first case study illustrates how a target was randomly missed in a direct fire application. A second is an indirect fire application, illustrating how variation in drift can be linked to yawing effects.

1. INTRODUCTION

An integral part of trajectory simulation is the stipulation of initial conditions. These are the position and velocity of the projectile with respect to the system of reference, as well as the orientation of the projectile (yaw) and the angular velocity.

In this paper we consider spin stabilized axis-symmetric projectiles and specifically focus on the effect of initial projectile orientation and angular velocity on the trajectory and the eventual impact positions. Possible yawing patterns are discussed. Simulation results of a six degree of freedom trajectory model illustrate how variation in initial angular motion influences projectile fall of shot. The simulation results are used to interpret impact results observed in direct and indirect firing trials.

We eventually discuss the possibility of minimising the effect of yaw on dispersion by controlling the orientation of initial yaw.

2. YAWING PATTERNS

2.1 Well-Launched Projectile

A projectile is well-launched when it leaves the barrel with no angular velocity (except for spin) and with the projectile axis parallel to the trajectory. Murphy [1] discusses the fact that a well-launched projectile initially possesses a small spiralling motion of the projectile axis about the trajectory due to gravitational bending of the trajectory. Although this influences the trajectory, we do not discuss it in this paper.

2.2 Projectile Launched with an Initial Pitching/Yawing Angle

Fig. 1 to 4 below display the first 2 seconds of the cyclic motion of a projectile launched with an angle of 4° between the projectile axis and the tangent to the trajectory. The orientation of the initial perturbation is different in each case.

The general motion of the projectile nose (projectile axis) is that of a decreasing spiral. The precession (large spiral motion) dominates the nutation (less pronounced choppy motion of the axis). This is the 6DOF equivalent of results discussed in [1].

In Fig 1 the projectile is launched with a pitching angle of +4°. Initially the projectile nose is directed to the right of the trajectory. The lift force imparts a velocity component to the right of the trajectory. Even though the projectile experiences a lift force to the left during later stages of the flight, the effect of the initial velocity to the right dominates and one may expect the projectile drift to be further to the right than would normally be expected with a well-launched projectile.

Likewise one would expect projectiles launched with the initial pitching angle of –4° to have a drift less than normal (Fig. 3). For the same reason projectiles launched with an initial yawing angle of +4° (Fig. 2) can be expected to range shorter than projectiles launched with an initial yawing angle of –4° (Fig. 4). In cases of indirect fire both can be expected to range shorter than a well-launched projectile due to the effect of the higher drag brought about by the initial yaw.

The qualitative discussion above will be demonstrated in Par 4.1 when investigating the effect of initial angular velocity on fall of shot.

2.3 Projectile Launched with an Initial Pitching/Yawing Velocity

Fig. 5 to 8 below display the first 0.5 seconds of the combined pitching and yawing motion of a projectile launched with a projectile axis angular velocity of 300°/s. The orientation of the angular velocity in each case is directed along the positive or negative direction of the pitch or yaw axes.

The general motion of the axis is now more complicated than in the case of an initial yawing or pitching angle as discussed previously. The precession is still that of a decreasing spiral. The nutation of the axis is however much more pronounced.

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In Fig. 5 the projectile is launched with a pitching rate of +300°/s. Initially the projectile axis is located below the trajectory. The lift force will impart a downward velocity to the projectile. Even though the projectile later experiences an upward lift force, the effect of the initial downward velocity dominates and one may expect the projectile to range shorter or impact lower than a projectile launched with a pitching rate of -300°/s (Fig. 7)

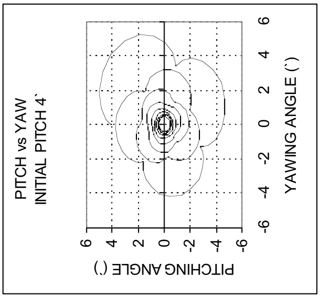
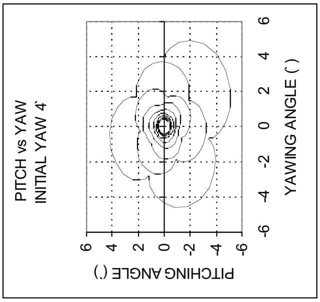


Figure 1.



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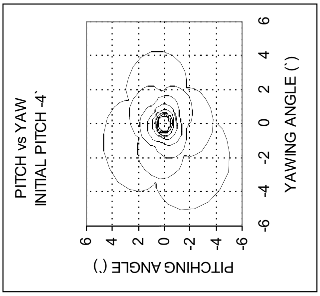

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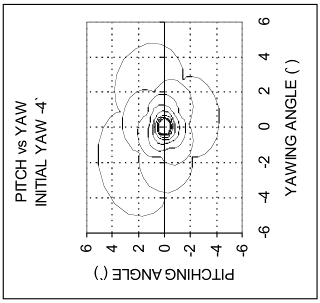

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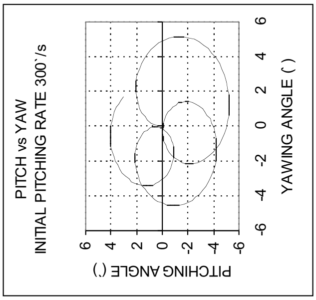

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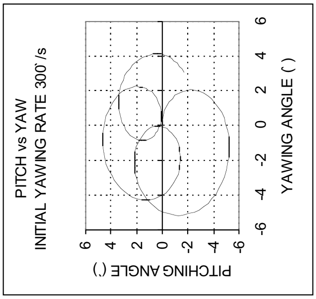

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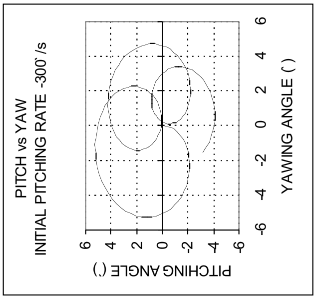

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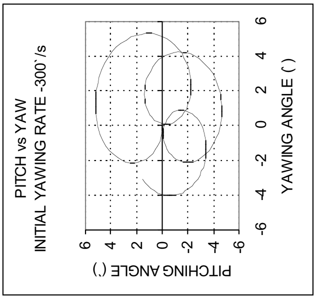

Figure 8.

for which an initial lift force induced upward velocity dominates. In the case of indirect fire both should however range shorter than a well-launched projectile due to the effect of higher initial drag caused by the projectile yaw.

Similar arguments lead to the conclusion that projectiles launched with yawing rates of +300°/s and -300°/s (Fig. 6 and 8 respectively) will have final drift values respectively less and greater than that of a well-launched projectile.

The qualitative discussions above are illustrated in Fig. 10 to 13 which follow from six degree of freedom simulations for the specific case studies discussed.

3. MEANINGFUL INITIAL CONDITIONS

Considering the projectile and barrel geometry, it is impossible for the projectile to exit the barrel at any significant yaw angle. The only possibility for a projectile to exhibit yawing motion during the initial stages of the trajectory, is for it to be launched with an initial angular velocity leading to the cyclic motion illustrated in Fig. 5 to 8.

This conclusion is supported by test range observations in the case yawing projectiles with a muzzle velocity > 800 m/s. The projectile yaw is characterized by a swish-swish sound which suggests that at times the projectile axis is far away from the tangent to the trajectory, while at times it is close to the tangent, which can be expected from projectiles launched with an initial angular rate.

4. INITIAL ANGULAR MOTION AND DIRECT FIRE APPLICATIONS

4.1 Simulations

Initial angular motion of a projectile directly impacts on the fall of shot pattern. Fig. 9 below illustrates the impact positions of a medium caliber HE projectile fired at a target at a range of 1000 m. The well-launched projectile impacts at the center of the target. Simulations were performed for initial angular velocities of 300°/s, 600°/s and 900°/s. For each of these the orientation of the plane of the initial yaw was varied from 0° with respect to the positive pitching plane to 315° in increments of 45°.

The results of the simulations confirm the previous qualitative analysis of projectile yawing patterns and the expected fall of shot (Par 2.3; Fig. 5 to 8).

Fig. 10 to 13 illustrate previous discussions regarding velocity components of projectiles launched with different orientations of the initial angular velocity (Par 2.2). In order to compile these figures the horizontal and vertical velocity components of a well-launched projectile were deducted from those of the yawing projectile.

Fig. 10 and 11 illustrate that with the initial plane of orientation of the angular velocity set at 0°, the mean vertical velocity is definitely lower causing the yawing projectile to impact below the center of the target. The difference in mean horizontal velocities is small leading to small deviations in projectile drift.

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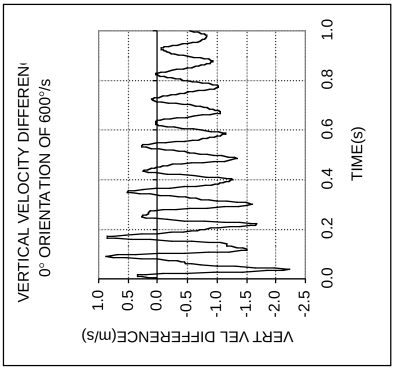

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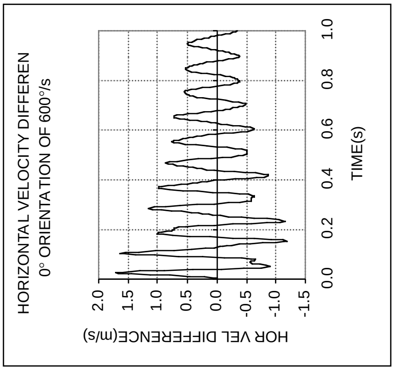

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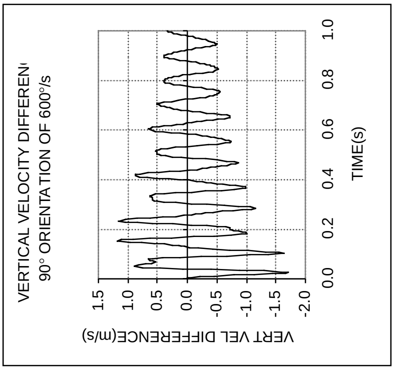

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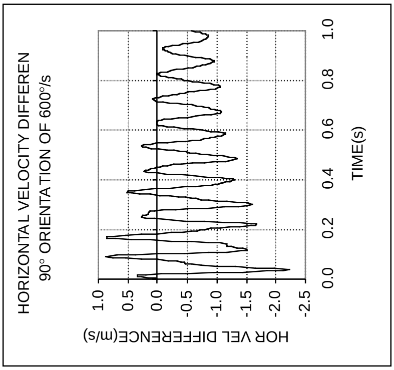

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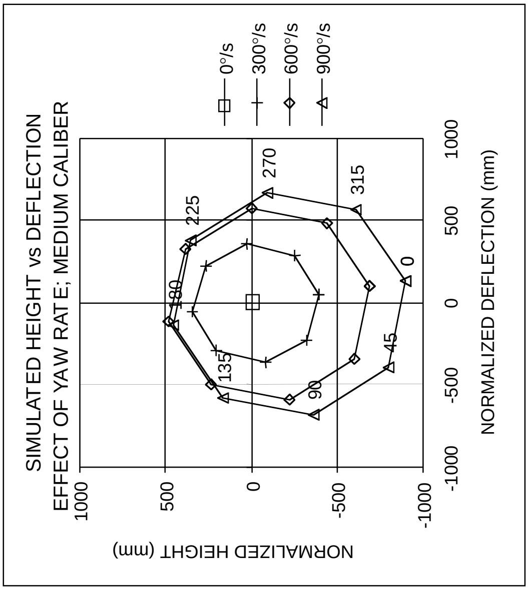

Figure 9.

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The results for a 90° orientation of the initial plane of yaw are illustrated in Fig. 12 and 13. Similar results account for the impact positions of projectiles with other planes of orientation of the initial angular velocity.

4.2 Case Study

In a medium caliber ammunition development program it was found that a specific projectile performed poorly in direct fire trials. The target was often missed at any of the four sides. Projectiles missing the target possessed very high retardation values due to being launched with high values of the initial yaw rate. Referring to Fig. 9 this fact, in combination with other factors such as lateral motion of the barrel at the moment of muzzle exit, explains why it was possible that the target could be missed.

5. INITIAL ANGULAR MOTION AND INDIRECT FIRE APPLICATIONS

5.1 Simulations

The qualitative effect of yaw rate and orientation as previously discussed (Par 2.2 and 2.3) applies to indirect fire applications as well.

Fig. 14 illustrates the effect of yaw rate orientation and magnitude on the fall of shot of an ERFB type projectile. The simulation was performed for an elevation of 500 mils. Yaw rates considered were 0°/s, 300°/s, 650°/s and 900°/s which lead to maximum yaw angles roughly of magnitude 0°, 5.5°, 13.5° and 19.5°. In the simulations the plane of (total) yaw orientation was set at 0° to 315° in increments of 45°.

Each simulated range and deflection was normalized by subtracting the range and drift of the 0° simulation from the specific simulated values.

Fig. 14 also contains an envelope which was constructed using the simulation results. If initial yaw rate was the only perturbation experienced by a projectile, it could be expected to impact within the given envelope.

In line with discussions in Par 2.2 and 2.3 projectiles with a 180° and a 0° plane of yaw rate orientation respectively range furthest and shortest, while those with a 270° and 90° plane of orientation respectively impact furthest to the right and left.

5.2 Case study

In [2] a method was discussed which uses initial retardation and impact data to compute the maximum value of initial yaw as well as a drag form factor for a yawing projectile. (It is assumed that the projectile is launched with an initial yaw in the 45° plane of orientation, and not with an initial angular rate. Standard data reduction techniques do not compute initial yaw. The entire variation in range is therefor attributed solely to variation in the drag form factor and consequently to drag variation along the entire trajectory.)

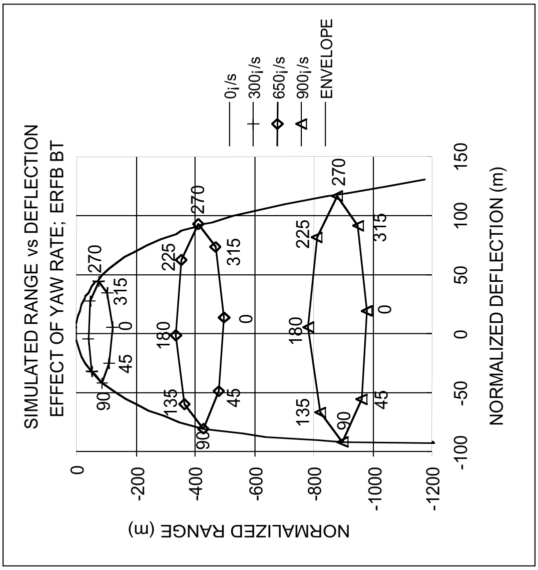

Figure 14.

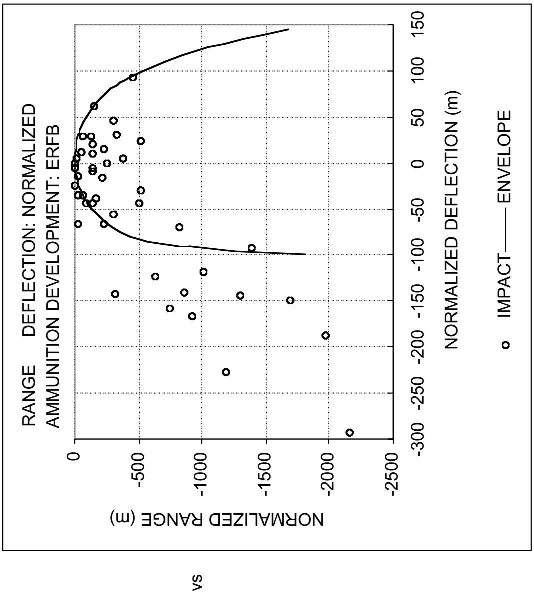

Figure 15.

In an ammunition development program three types of ballistic similar ERFB BT projectiles were fired at 500 mils elevation. Retardation varied from acceptable to poor. Dispersion of the group was shocking. The data reduction method of [2] was used to find a drag form factor and maximum yaw value for each projectile fired. In order to compare experimental data and simulation results, experimental data was normalized with respect to projectile mass, muzzle velocity and drag form factor. In line with the construction of

Fig. 14 range and drift values of the projectile with the highest range were deducted from the values of the other projectiles. The manipulated results are shown in Fig. 15 together with the computed envelope given in Fig. 14.

The results in Fig. 15 are promising in that only 12 of the 44 shots have normalized impact positions far removed from the envelope. The rest of the impact positions are either inside or very close to the envelope.

One can conclude that if the yaw computations are acceptable, other factors such as observed projectile damage or lateral movement of the barrel at launch are responsible for the unexpected impact positions of the 12 projectiles. The fact that all of them ranged short and to the left of the ideal impact position, points to the presence of a systematic launch problem which was present for these projectiles.

The data reduction rendered initial yaw values less than those predicted by the 6DOF model, because [2] assumes initial yaw in stead of initial angular rate. Referring to Fig. 1 to 4 (initial yaw) and Fig. 5 to 8 (initial angular velocity) it is understandable that for the same eventual maximum yaw value, the initial yaw condition has a greater effect on range and drift than the initial angular velocity condition. Inversely, in order to get a specific range/drift effect, the maximum yaw value relating to a condition of initial yaw is lower than that relating to an initial angular rate condition.

6. DISPERSION CONTROL BY MEANS OF YAW CONTROL

In principle it is possible to minimize the effect of yaw on dispersion if one is able to control the plane of initial projectile yaw. Referring to Fig. 9 and 14 dispersion is least influenced by yaw if the plane of yaw is such that projectiles exit the barrel with a negative pitching rate. This idea adds an interesting angle to the design of gun systems.

7. ACKNOWLEDGEMENT

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8. REFERENCES

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2. W.J. Rossouw, “The role of zero yaw drag, yaw drag and pitch damping in data reduction”, *15th International Symposium on Ballistics,* Jerusalem, Israel, 1995