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# JUMP ERROR & GUN DYNAMICS: A COMPARISON BETWEEN TWO TYPES OF 120MM SMOOTH-BORE TANK GUNS

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This study describes a methodology for comparing two types of tank guns regarding their accuracy performance and dynamic behaviour. Several approaches were used in order to examine and compare the two gun types. Experimental jump firing data for APFSDS ammunition and the corresponding tube curvature data were statistically analyzed. An empirical model that correlates jump error with tube curvature was obtained for each gun type in order to understand the sources of the different jump variability between them. In another approach a numerical simulation of the tube-projectile interaction was conducted in order to compare the dynamic behaviors and projectile impact point of the two gun types. The findings of this study indicate that tube curvature is the most dominant factor that governs jump error. Dynamic behaviour derived from design differences between the gun types had negligible influence on jump error.

## INTRODUCTION

Over the last three decades of research in the field of tank gun dynamics [1, 2], much progress has been achieved in understanding the physical phenomena that determine the accuracy of tank main gun systems. Numerical simulations were developed to describe the gun motion and tube-projectile interaction during launch [3-5]. Experimental techniques and test instrumentation were set up to measure and quantify physical parameters associated with jump error [6]. These two complementary approaches, along with an adequate validation methodology [7], provide a research infrastructure that enables isolation of jump components and optimization of gun and projectile design parameters to improve system accuracy [8-9].

A new way of treating the jump phenomenon is by obtaining an empirical model, based on a large amount of experimental jump data [10]. The linear model correlates between tube curvature and measured jump values, thus allowing it to be used in the prediction of jump and the improvement of gun accuracy.

In the current paper, a comparison between accuracy performances of APFSDS ammunition fired from two different types of 120mm smooth-bore tank guns is described. The major incentive for this work was a noticeable difference in jump error variability between tanks on which the two gun types were mounted. This characteristic of jump variability is very important and may have an effect on the tank calibration policy. Obviously, lower jump variability is desirable in order to attain a higher degree of uniformity of the tank fleet. Furthermore, as has been suggested [8, 11], low jump variability may indicate a reduced sensitivity to occasion-to-occasion errors, thus resulting in a higher level of accuracy.

The main purpose of the present study is to understand the origin of the different jump variability of the two guns. Causes for this phenomenon may be attributed to the different dynamic behaviour due to design variations in the recoil mechanism or varying characteristics of the tube curvature profiles.

## GUN DESIGN DESCRIPTION

The two types of 120mm smooth-bore tank guns under discussion are different designs of the IMI, where gun type B is an improved version of gun type A (see Fig. 1), developed to achieve a higher ability to absorb recoil energy imposed by improved KE ammunition. Gun type B differs from gun type A in the following parameters: longer recoil length due to geometric changes in the recoil mechanism; recoil parts weigh 3% more; bore rider distance is 9% shorter.

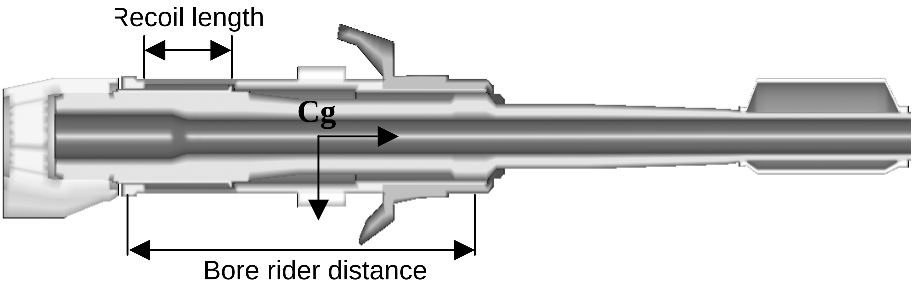

Figure 1. Schematic description of gun type A

## EXPERIMENTAL DATA ANALYSIS

In order to compare the experimental data of the two gun types, equal numbers of gun tubes were selected randomly from each type. Jump errors derived from direct firing jump tests are displayed in Fig. 2, where each point represents the calculated jump for a specific tube, based on the mean point of impact (MPI) of a shot group. A qualitative examination of the results indicates that the jump variability of gun type B is significantly smaller than gun type A’s. A quantitative analysis shows a small difference between the average jump or center of impacts (COI) of the two gun types. On the other hand, the jump variability (in terms of standard deviations) is 48% and 36% less in gun type B in the vertical and horizontal axes, respectively. These results may have a crucial influence on tank fleet calibration policy: low jump variability may support a single, "fleet zero" computer correction factor (CCF) for the APFSDS ammunition, while high jump variability could require an individual CCF for each tank in order to avoid large systematic errors and maintain tank fleet accuracy.

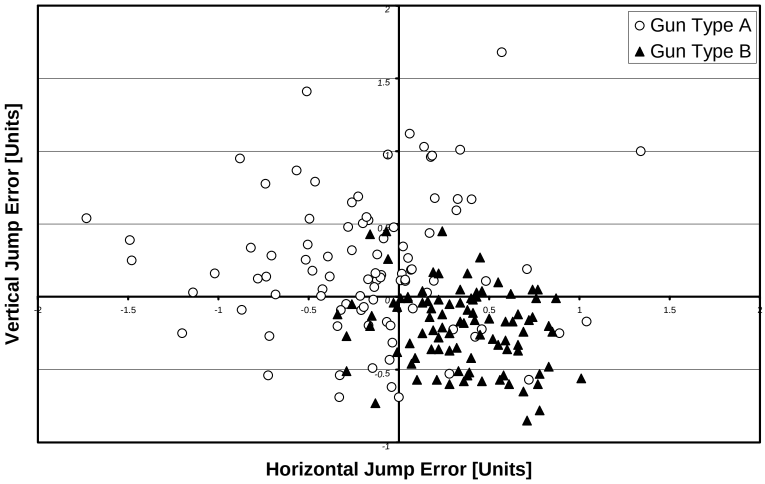

Figure 2. Jump error results for the two gun types

Due to the known effect of the tube shape on gun dynamics, the next step in the study was to examine tube curvature profiles of the selected samples for the two gun types. The measured curvature is presented as vertical and horizontal centerline deviations, relative to the origin of the shot (forcing cone), at the rear face of the tube (RFT). Centerline displacement on the vertical axis is shown in Fig. 3. As is apparent from the figure, gun type B’s tube shapes are more uniform in comparison to gun type A’s. Similar results were observed for the horizontal axis. Averages and standard deviations of the measured displacements, at five discrete points along the tube were calculated. As may be seen from the results in Table 1, mean displacements are of the same order of magnitude for the two gun types, while standard deviations of the measured points are significantly smaller for gun type B, indicating a more uniform distribution of the curvature profiles of the tubes.

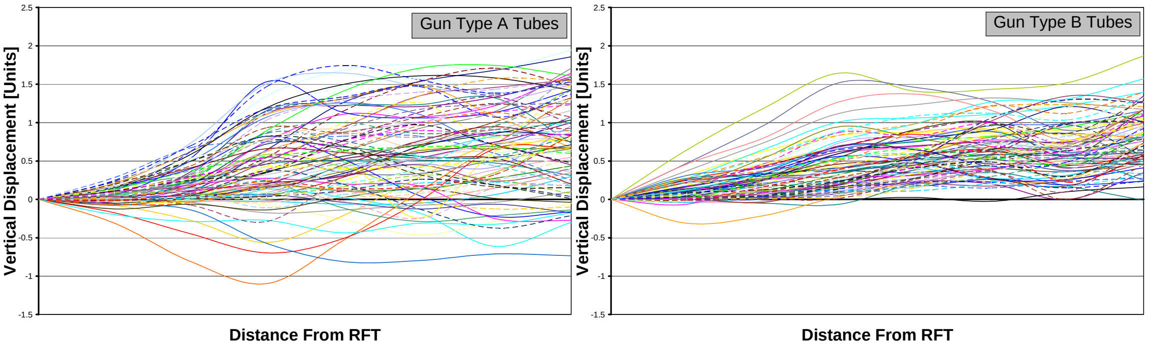

Figure 3. Vertical tube curvature for the two gun types

Table 1. Tube shapes comparison - Mean and S.D of measured centerline displacements

| Centerline displacements along the tube | | Vertical Plane [Units] | | | | | Horizontal Plane [Units] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| **Gun Type A** | **Mean** | 0.04 | 0.42 | 0.55 | 0.62 | 0.76 | 0.02 | 0.14 | 0.15 | 0.14 | 0.16 |
| | **S.D** | 0.10 | 0.50 | 0.53 | 0.56 | 0.59 | 0.11 | 0.56 | 0.57 | 0.54 | 0.53 |
| **Gun Type B** | **Mean** | 0.09 | 0.41 | 0.54 | 0.64 | 0.80 | 0.02 | 0.09 | 0.14 | 0.20 | 0.23 |
| | **S.D** | 0.13 | 0.33 | 0.30 | 0.31 | 0.35 | 0.14 | 0.35 | 0.37 | 0.43 | 0.41 |

The above results point to a possible correlation between jump variability differences and tube curvature characteristics of the two guns.

In order do examine the effect of the gun design (dynamics) on the jump error, multiple pairs of shot groups fired from tubes with similar profiles, but from different gun types, were compared. The pairs were selected on the basis of the minimum least squares differences between the tube curvatures. The comparison showed that the mean difference of jump errors within the pairs is of the same magnitude as the previously known occasion-to-occasion error, typical to these gun types. This implies that the design changes between the two guns have an insignificant effect on the jump error relative to the tube curvature factor.

## Linear Jump Prediction Model

Another approach in validating the above findings is to obtain an empirical prediction model, based on a large amount of experimental jump firing and tube curvature data. The model provides a linear relationship between tube curvature and jump error, as detailed thoroughly in [10]. Separate multi-dimensional linear models were established for the vertical and horizontal axis of each gun type, describing predicted jump values as a function of tube curvature, as follows:

$$Jump(Horizontal) = a_0 + \sum_{i=1}^{n} a_i \cdot x_i \quad ; \quad Jump(Vertical) = b_0 + \sum_{i=1}^{n} b_i \cdot y_i \tag{1}$$

where $x_i$, $y_i$ are the measured horizontal and vertical centerline deviations, $a_0$, $a_i$ and $b_0$, $b_i$ are empirical coefficients and $n$ is the number of measurement points along the tube. The empirical coefficients of the models were derived from a linear regression, based on the least squares method, followed by a correlation coefficient calculation ($R$):

$$R = \sqrt{1 - \frac{(Std.Err)^2}{\sigma^2}} \quad ; \quad Std.Err = \sqrt{\frac{\sum_{i=1}^{N} \left(Predicted_i - Observed_i\right)^2}{N-1}} \tag{2}$$

where $\sigma$ represents the standard deviation of observed jump values, *Std.Err* is defined as the model error, $N$ is the number of experimental jump values. Calculated $R$ values are presented in Table 2, indicating an adequate degree of correlation in both axes. Lower $R$ values obtained for gun type B are associated with its lower jump variability, which approaches the accuracy limit of the model. The remaining errors such as jump occasion-to-occasion error, inaccuracy in tube curvature measurements and other physical factors (such as sabot discard) which contribute to jump, are not included in the model and hence limit the accuracy of the model.

Table 2. Correlation coefficient *R* for the empirical prediction models

| **Correlation Coefficient *R*** | **Vertical Axis** | **Horizontal Axis** |
|---|---|---|
| **Gun Type A Model** | 0.82 | 0.87 |
| **Gun Type B Model** | 0.64 | 0.81 |

After the two sets of model coefficients were established, we applied the model coefficients of gun type B to curvature data from gun type A tubes and viceversa. The results showed that prediction errors and therefore correlation coefficients remained similar to those of the original models. With this procedure, the resulting R values after applying the gun type B model to the gun type A tubes, were 0.79 and 0.84 in the vertical and horizontal axes, respectively. Since a prediction model that was obtained for one gun type is applicable to the other, the effect of tube curvature on jump error is similar for both gun types. This validates the above assumption that the difference in jump variability between the gun types is almost totally explained by different distributions of their tubes curvature profiles, while the physical effect of the changes in the gun designs is negligible for the APFSDS ammunition.

## NUMERICAL SIMULATION

### 3D Gun Dynamics Model

The numerical simulation was built in order to deepen our comprehension of the gun dynamics during the in-bore travel and its effect on the target impact point. This simulation allowed us to clearly separate the factors which govern jump error and to compare between the two gun types.

Numerical models of the two gun types and the APFSDS ammunition were built via the LS-DYNA hydro-dynamic code [10]. All of the gun's major components such as tube, breech, cradle recoil mechanism, rotor and bearings were modeled in finite elements. The trunnions and the elevating mechanism were constrained to a fixed point in space to simulate a rigid mounting to the carriage. Manufacturer's drawings and inspection data were considered in order to model clearances and masses as best as possible. The APFSDS projectile (penetrator, tail, and sabots) was added to the model, and the propelling force acting on its base during launch was derived from the experimental pressure curves. Models validation was performed by comparing several calculated gun dynamics parameters (recoil length and velocity, recoil force and projectile exit time) with their experimentally measured values.

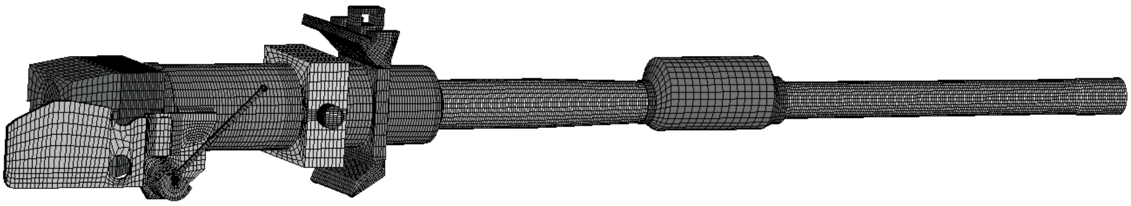

Figure 4. Finite elements gun type B model

Once the modeling effort had been completed, a "breech-to-target" simulation methodology was implemented to calculate the theoretical mean impact point [7-10]. First, the dynamic state of the projectile at muzzle exit (e.g. projectiles transverse velocity and angular rate around its center of gravity) was obtained and recorded from the gun dynamics simulation, and then utilized to determine the initial conditions for a 6-DOF ballistic trajectory simulation.

13 different actual tube centerline profiles were incorporated into the models and runs were performed comparatively for each gun type and tube combination. Gun dynamics simulations showed a similar muzzle pointing angle for the two gun types

during launch. Since muzzle pointing angle is determined by the angular motion of the cannon about the trunnions during firing, a high degree of compatibility at shot exit (Fig. 5) indicates that the torque moment induced by firing the APFSDS ammunition and the corresponding dynamic response are similar in both guns, despite the differences in their recoil mechanism.

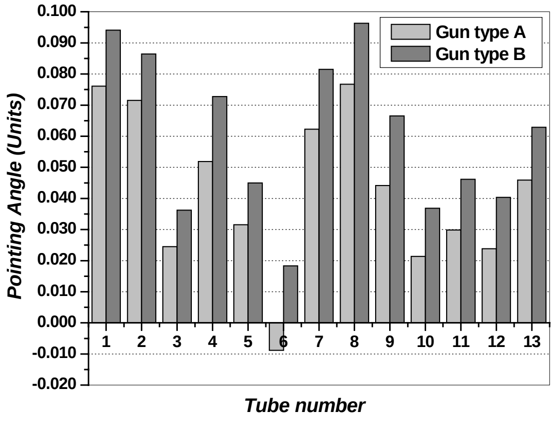

Figure 5. Muzzle pointing angle at shot exit – simulation results

Impact point simulation results are presented in Fig. 6, showing a good match between the two guns. These simulation results support the previous contention that gun design changes led to minimal jump error differences between the two gun types.

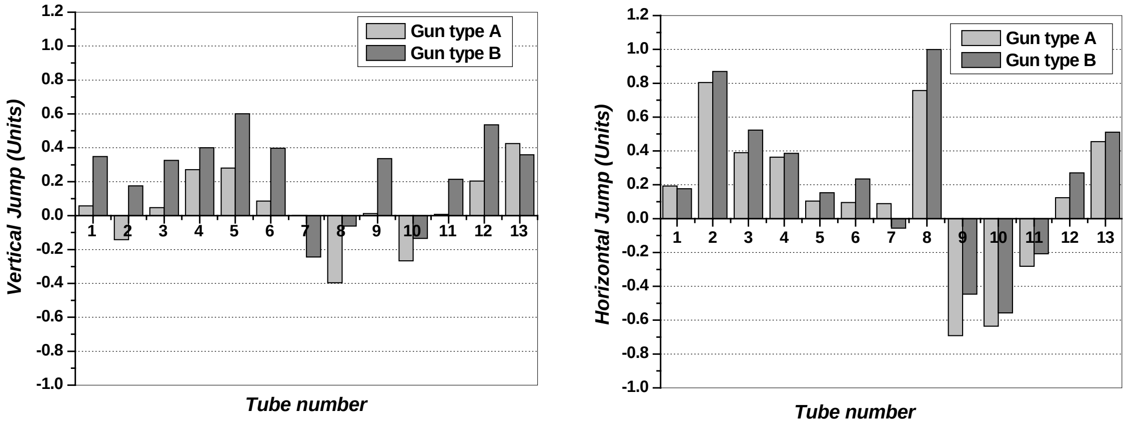

Figure 6. Simulated target impact points

## CONCLUSION

In this study, a methodology for comparing two different tank gun designs, regarding their accuracy performance has been demonstrated. The methodology uses both experimental data analysis and numerical simulation techniques to investigate the sources of a different jump error variability of the two gun types. The experimental data analysis showed that gun type B`s smaller jump variability may be explained by a higher uniformity of its tube centreline profiles. Implementation of a jump prediction model suggested a similar correlation between jump error and tube curvature for both gun types. "Breech-to-target" simulation runs showed a high level of compatibility in launch dynamics and theoretical impact points when firing the APFSDS ammunition from the two guns. The above results lead to the conclusion that despite the design changes, no significant difference in the dynamic behaviour of the two gun types was identified. We may therefore conclude that the dominant source of jump variability differences is related to different tube centerline profiles characteristics.

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