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Effects of Projectile and Gun Parameters on the Dispersion

Tolga Dursun

ASELSAN Inc. MGEO Division, Akyurt, Ankara - 06750, Turkey
E-mail: tdursun@aselsan.com.tr

ABSTRACT

Main battle tanks constitute one of the most powerful fire powers for the armoured land forces. To use this very high fire power efficiently, the dispersion of shot impacts becomes crucial. Dispersion is affected by the aerodynamic factors, gun-projectile interactions, projectile and gun dependent factors, manufacturing tolerances and environmental factors. The change in aerodynamic factors and environmental conditions varies the aerodynamic forces applied on the projectile and this affects the dispersion characteristics of the projectile. In this study, the effects of the changes in recoil stiffness, gun support stiffness, projectile muzzle velocity and manufacturing tolerances of projectile forward/rear bourrelet diameters on the dispersion for 120 mm L44 and L55 calibre guns are investigated. Armour piercing fin stabilised discarding sabot type projectile is used in the analysis. Statistical dispersion analyses including interior ballistic, in-bore balloting and exterior ballistic analyses are conducted using PRODAS ballistic software. According to the results, it is determined that the decrease in projectile/bore clearance (forward/rear bourrelet diameter) results in improved dispersion of ammunition. The 10% changes from the nominal recoil stiffness and the vertical support stiffness values have negligible effects on the dispersion. In addition, the results show that muzzle velocity variations influence the dispersion in vertical direction substantially. Using the procedure applied in this study, it is shown that different clearance conditions can be analysed and most suitable tolerances may be determined taking into consideration of both the gun system performance and manufacturability.

Keywords: Gun dynamics; Muzzle velocity; Recoil stiffness; Dispersion

1. INTRODUCTION

Main battle tanks constitute one of the most powerful fire powers for the armoured land forces. Higher fire power is achieved by higher rate of fire, higher range, higher effect on the target and better weapon system accuracy and lower dispersion. Accuracy depends on gun droop, sighting boresight, gun wear, ammunition (finish, shape, weight, propellant, and charge temperature), crew, meteorological conditions, survey (map, height and location of the gun and target) and prediction (drag law, trajectory calculation and limited data). On the other hand dispersion is affected by the factors which occur from propellant ignition to target impact. Projectile mass variations, the offset between the projectile centre-of-gravity and the barrel centreline, the change in chamber pressure due to propellant burning process, clearance between the obturator and gun barrel inner diameter, projectile manufacturing tolerances, the clearance in the cradle trunnion bearings, the clearance in the gun thrust bearings, the change in recoil force and the gun barrel geometry (curvature), and meteorological conditions (temperature, pressure, wind, precipitation and humidity) may cause changes in impact point on the target which result in the increase of the dispersion[1,2,3].

Gun-projectile interaction has been investigated through large amount of researches. Experimental setups, analytical and finite element models have been developed to simulate the gun-projectile interaction and to examine the sensitivity of parameters on the dispersion[4-22].

The effects of gun barrel length on the firing accuracy have been investigated while the tank was on the move[8]. Three barrels with different lengths were used. It was found that as the travelling speed of the tank increased the difference in dispersion between the shortest and longest barrel increased due to the flexibility of the barrel.

The influence of the balanced and unbalanced breech has been investigated by performing experiments and simulations[9,10]. It was shown that gun movement varies from shot to shot significantly for the gun with the unbalanced breech leading to considerable changes in the muzzle exit conditions. It was also noticed that a balanced breech gun system has reduced sensitivity to different tube centreline profiles, muzzle velocity and propellant temperature variations.

The sabot front borerider stiffness values have been changed and its effect combined with the manufacturing tolerances on the dispersion of 120 mm APFSDS projectile has been examined analytically[12,13]. The simulations showed that projectile with softer sabot front borerider has more effect on the dispersion and the gap between the projectile and gun bore caused the projectile to tilt its principal axis off the bore centreline resulting in variations in muzzle exit conditions.

The dynamic interaction between the gun barrel and accelerating projectile during firing has been analytically examined[19,20]. The effects of projectile mass, exit velocity, acceleration effects and barrel inclination angle on the muzzle

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displacements have been determined.

The effects of the projectile mass, mass eccentricity, dynamic unbalance, the load deviation, and the clearance between the projectile and the bore on the muzzle disturbance of a gun barrel has been analysed using orthogonal test method[22]. It was observed that projectile loading offset on the muzzle disturbance is most significant. In addition, it was concluded that clearance between the projectile and the bore changes the muzzle disturbance significantly and affect firing dispersion.

In-bore motion of the projectile and propellant gas pressure cause forces on the gun and this interaction results in the dynamic lateral motion of the barrel. The in-bore projectile motion is also affected by the initial orientation of the projectile. The projectile is never positioned exactly the same way inside the bore on each successive shot due to diametral and runout tolerances. Dynamic motion of the projectile/gun tube system is characterised by lateral acceleration, bending, angular rates, tube motion and tube pointing. In-bore dynamic analyses have been performed using LS-DYNA and PRODAS software in order to determine both the muzzle exit conditions (yaw angle, angular rate, and transverse velocity) and the most influential sources on the dispersion have been pointed out[23].

An analytical method has been applied to determine the effect of muzzle velocity variations on the dispersion taking into account the air drag, gravity drop and crosswind[26]. It was found that the muzzle velocity variation, in combination with gravity effect, becomes a significant parameter in determining dispersion in the elevation direction.

Statistical in bore balloting motion analysis, external ballistics Monte Carlo simulation and six degree of freedom trajectory analysis have been carried out to determine the effects of initial yaw/pitch rates, yaw/pitch dampening, plane start angle, launch spin, clearance, centre of gravity shift, dynamic imbalance angle and cross wind[27]. It was suggested that plane start angle of projectile affects first maximum yaw and projectile should then be aligned in-line with the barrel centreline. It was observed that clearance between the driving band and gun bore controls the residual spin and has an effect on dispersion but changes in stiffness of the barrel and projectile front/rear bore riders, wheel base, muzzle velocity, pressure profile and location of obturator have less effect on yaw rate and dispersion.

Although there exists large amount of studies on this subject, the subject is open to research because of the significant number of parameters affecting the projectile dispersion. It is also a hot topic to investigate the differences of gun dynamic responses of different calibre tank guns. To this end, in the present study, only the effects of the changes in recoil stiffness, forward gun support stiffness, muzzle velocity and projectile forward/rear bourrelet diameters on the dispersion for the 120 mm L44 and L55 calibre guns are studied but the other effects mentioned above including the external ballistics related factors are not considered here. In addition, except for variations in projectile drag, and down range wind effects, the dispersion is independent of the range and it is defined in terms of angle, consequently contribution of the range has not been considered. The considered parameters may frequently change from firing to firing due to the following reasons. Although hydro-pneumatic types of recoil mechanisms are widely used in combat vehicles, the performance of these system are affected by terrain/weather conditions and the change in the performance of the recoil mechanism may affect the consistency of the gun system[23]. Forward gun support stiffness may change due to the joint clearances inherent to the joint design and/or wear. Muzzle velocity changes occur due to the changes in propellant burn rate, propellant temperature, manufacturing tolerances, and wear of the gun bore etc. When the projectile is inserted into the gun tube, the initial position it takes inside the tube due to tolerances affects its initial maximum yaw which directly influences the dispersion. In addition, the tolerances of the forward/rear bourrelet diameters affect the motion of the projectile while travelling in-bore which causes different muzzle exit conditions.

Since the projectile launching is a highly dynamic event and in high velocity projectile/gun systems very small changes can result in increased dispersion, experimentally determination of the effects of the aforementioned parameters by firing tests is both very expensive, time consuming and very difficult to realise. Simulation becomes the only possible method to completely understand the effects of each parameter on the dispersion characteristics of the projectile/gun system. To this end, PRODAS ballistic software is used to model the projectile/gun system and to carry out simulations in order to identify the effects of these parameters on the projectile dispersion.

2. MATERIAL AND METHOD

PRODAS ballistic software is used for the internal ballistic, in-bore projectile motion (balloting) and the exterior ballistic analyses. The model used in the analyses consists of flexible gun barrel and projectile, recoil spring, barrel-projectile contact springs at bore riders (bourrelet), and forward/rear horizontal/vertical gun support springs. For in-bore projectile motion analysis, PRODAS uses a finite element lumped parameter code that has the capability of modelling flexible projectile's motion inside a flexible gun barrel. Models of the projectile and the barrel are converted into lumped parameter models made up of nodes and two-noded beam elements.

Armour piercing fin stabilised discarding sabot (APFSDS) type projectile is used in the analyses. A representative view of APFSDS is shown in Figure 1.This type of ammunition has long slender, very heavy penetrator and a muzzle velocity between 1.5 to 1.8 km/s.

The nominal muzzle velocities of the projectile used in the present study are taken as 1705 m/s and 1760 m/s fired from L44 and L55 calibre guns, respectively. Baer-Frankle method is used for internal ballistic analysis to simulate combustion of propellant and to calculate the time-dependent base pressure (forcing function). The propellant and ignitor used in the analysis are selected from the PRODAS library as JA-2-120 mm and M125-120 mm electric primer respectively.

A rigid body 6 degree of freedom (dof) trajectory model is used to predict the free flight trajectory of the projectile. The aerodynamic coefficients and mass properties of the projectile required for the trajectory analysis are generated in PRODAS software. The effects of the both sabot separation and muzzle blast on the dispersion are not taken into account in the present

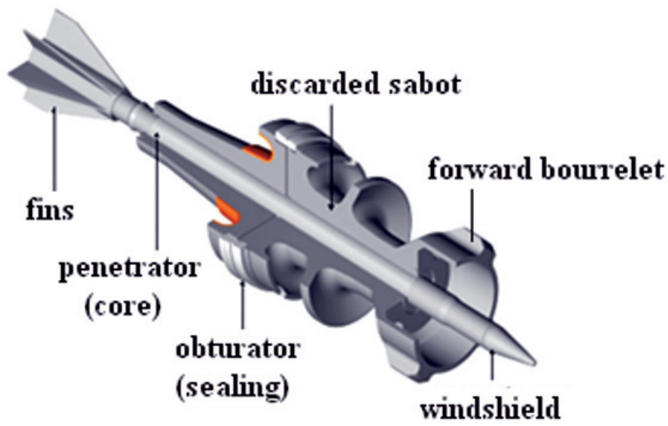

Figure 1. Armour piercing fin stabilised discarding sabot (APFSDS) projectile[25].

study. The dispersion analysis used in PRODAS includes muzzle exit parameters (muzzle exit yaw, yaw rate, transverse velocity), transition parameters (sabot separation, boresight), free-flight parameters (muzzle velocity, aerodynamic jump, aerodynamic trim angle, crosswind, aerodynamic/mass asymmetries) and manufacturing tolerance parameters. The general parameters related to the manufacturing tolerances used in dispersion analysis in PRODAS are as :

- Forward bourrelet diameter
- Forward bourrelet diameter standard deviation
- Forward bourrelet runout
- Forward bourrelet runout standard deviation
- Rear bourrelet runout
- Rear bourrelet runout standard deviation
- Sabot inner diameter at forward bourrelet
- Sabot inner diameter standard deviation at forward bourrelet
- Core outer diameter at forward bourrelet
- Core outer diameter standard deviation at forward bourrelet

A stochastic approach is conducted for the prediction of dispersion. Dispersion analysis flowchart followed in PRODAS software is as shown in Fig. 2.

The projectile is initially misaligned within the gun tube due to manufacturing tolerances. This misalignment produces secondary forces causing transverse displacement and yawing motion of the projectile as it travels from breech to muzzle. Multiple analyses are run to determine the muzzle exit conditions. The resulting yaw angle, angular rate and transverse velocity at muzzle exit are used in combination with transition sensitivities and free-flight sensitivities for their effect on dispersion.

The projectile and gun models prepared in PRODAS software are as shown in Fig. 3. In the projectile model, the obturator+rear bourrelet (#1) and front bourrelet (#2) contact stiffness are modelled as linear and non-linear springs respectively. The reason is, the obturator fits the barrel inner diameter firmly with no clearance in order to prevent the leakage of burning gas, on the other hand for the front side there is a small clearance between the front bourrelet and the inner diameter of the barrel. To simulate both the gap and contact between the front bourrelet and bore, a nonlinear spring model is used.

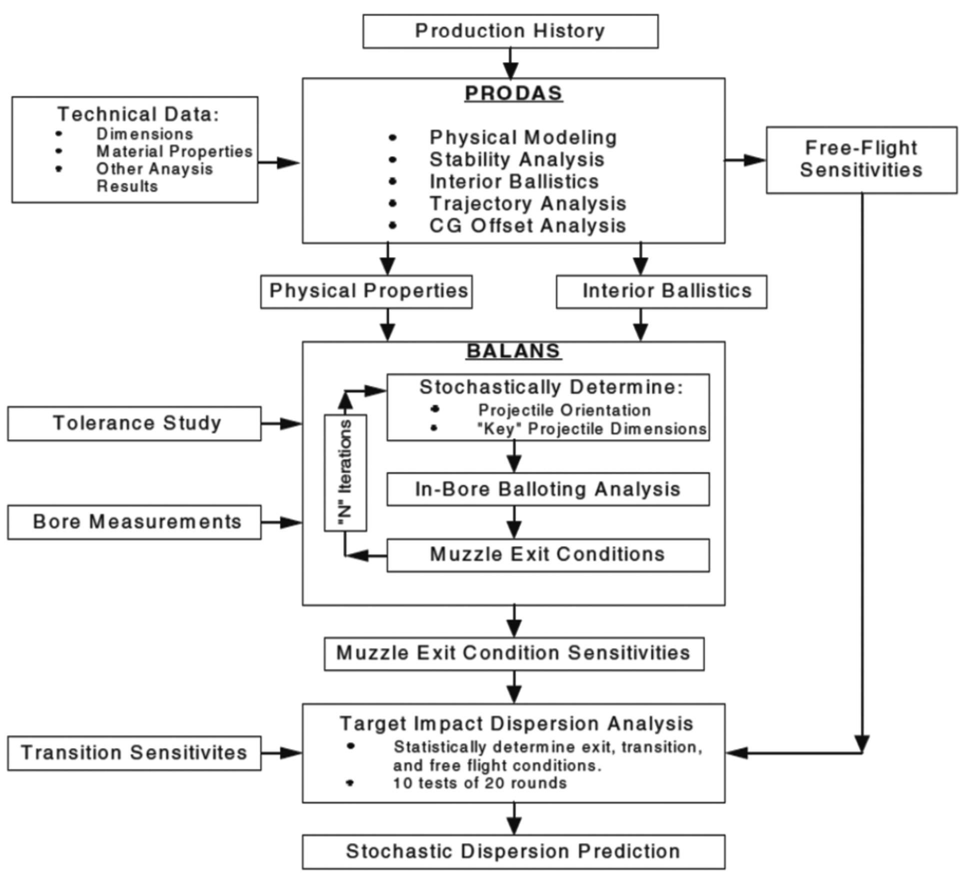

Figure 2. Dispersion analysis flowchart[23].

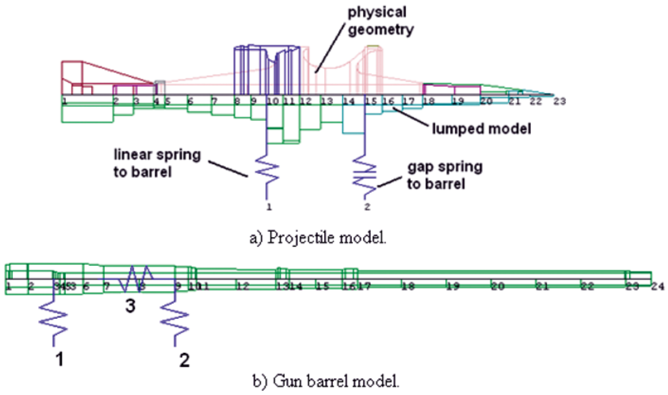

Figure 3. PRODAS projectile and gun models.

In the gun barrel model, the rear spring (#1) stiffness corresponds to the rear support stiffness and the front gun spring (#2) stiffness corresponds to the forward support stiffness. The spring (#3) stiffness corresponds to the recoil stiffness. The first two springs have components in vertical and horizontal directions and the third spring has only component in axial (firing) direction.

The gravity effect is taken into account in the analysis. Therefore, the analysis is performed in two steps. In the first step the gravity load is applied to the barrel and the barrel deflects at the end of this load step. In the second step, gun dynamics analysis is performed using the deflected gun barrel shape. Bore centreline profile is assumed as straight and bore diameter is taken as 120.00 mm and constant through the length of the barrel. The statistical dispersion analysis is performed with 500 iterations and with an integration time step size of 0.001 msec in order to obtain accurate results.

In the dispersion analysis, standard deviation of muzzle velocity is taken as 0 m/s and 10 m/s whereas 10% of change in recoil and forward vertical support stiffness are examined. The diameter of the forward bourrelet is taken as 119.5 mm and 119.7 mm. The standard deviation of the forward bourrelet diameter is taken as values between 0.03 mm - 0.5 mm. The runout of the forward bourrelet is taken as 0.15 mm, whereas runout of the rear bourrelet is taken as 0, 0.1 mm and 0.15 mm. The effects of the changes in the parameters are analysed in combination to estimate the target impact dispersion.

3. RESULTS AND DISCUSSION

According to the analyses the calculated total dispersion values are as given in Tables 1-5. Analyses results due to the combined effects of recoil stiffness, vertical forward support stiffness and forward bourrelet diameter changes are as listed in Table 2. Only the ratios of both recoil and vertical stiffness to the nominal values are given in all the tables due to the confidentiality of this information. In that analysis the muzzle velocity (MV) changes are kept zero. According to the results it is seen that when the clearance between the sabot and gun bore is high that is when the forward bourrelet diameter is low and its standard deviation is high, then the dispersion increases in both L44 and L55 calibre guns. The dispersion value is three times higher for forward bourrelet diameter of 119.5 mm and its standard deviation of 0.5 mm, compared to the configuration of forward bourrelet diameter of 119.7 mm and its standard deviation (std dev) of 0.03 mm or 0.1 mm. The 10 per cent changes in the recoil and the vertical stiffness values have insignificant effects on the dispersion. Dispersion values obtained according to the configurations as given in Table 1 are nearly the same for both L44 and L55 guns. In addition, the dispersion values in horizontal and vertical directions are almost the same. Since the dispersion values for the forward bourrelet diameter of 119.7 mm are the same for the forward bourrelet diameter standard deviation of 0.03 mm and 0.1 mm, then the designer may choose the standard deviation of 0.1 mm for the forward bourrelet diameter to obtain the same performance with optimum production cost.

The results of the dispersion analyses where the combined effects of the changes in muzzle velocity, forward bourrelet diameter and the changes in recoil stiffness and vertical stiffness are considered are as shown in Table 2.

Due to the muzzle velocity changes the dispersion in vertical direction increases substantially compared to the conditions as given in Table 2 for both calibre guns. Therefore, muzzle velocity changes should be controlled for better gun shooting performance.

In Table 3, only the effects of forward bourrelet diameter changes on the dispersion are listed.

For two different forward bourrelet diameters (119.5 mm, 119.7 mm), the standard deviations are taken between 0.03 mm – 0.5 mm. The results show that for the diameter of 119.5 mm, when the standard deviation is increased from 0.03 mm to 0.5 mm the dispersion in both directions increases nearly two times but for 119.7 mm nominal diameter, the dispersion increases more than three times. For the cases where the standard deviation of forward bourrelet diameter is less than 0.4 mm, the dispersion is not affected considerably.

In Figure 4, the change of dispersion due to forward bourrelet diameter standard deviation variations is shown for two calibre guns for the forward bourrelet diameter of 119.7 mm.

In Table 4, the results of the dispersion analysis due to the changes of the muzzle velocity and forward bourrelet diameter for two forward bourrelet diameters in L44 and L55 guns are shown.

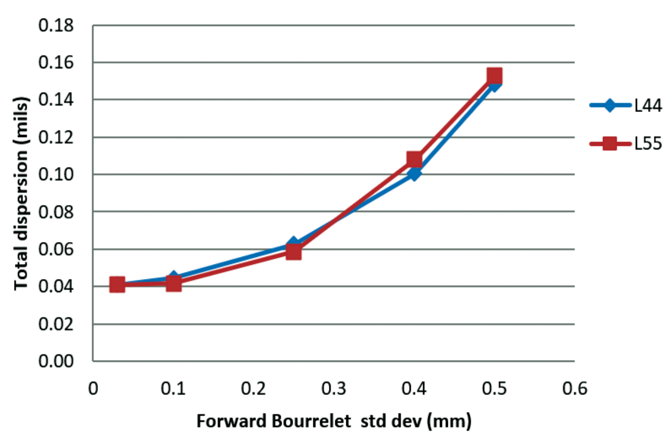

Figure 4. The change of dispersion due to forward bourrelet diameter standard deviation variations.

Table 1. Dispersion analysis results due to stiffness and forward bourrelet diameter changes.

Forward bourrelet diameter (mm)	Forward bourrelet std dev (mm)	MV Std dev (m/s)	Recoil stiffness ratio	Vertical stiffness ratio	Dispersion			
					L55		L44	
					Horizontal (mils)	Vertical (mils)	Horizontal (mils)	Vertical (mils)
119.5	0.1	0	1	1	0.045	0.046	0.051	0.046
			0.9	1	0.046	0.046	0.050	0.049
			1	0.9	0.048	0.047	0.050	0.048
			0.9	0.9	0.046	0.048	0.050	0.050
119.5	0.3	0	1	1	0.055	0.057	0.055	0.055
			0.9	1	0.053	0.052	0.055	0.054
			1	0.9	0.056	0.055	0.057	0.059
			0.9	0.9	0.053	0.051	0.055	0.058
119.5	0.5	0	1	1	0.073	0.082	0.077	0.087
			0.9	1	0.080	0.073	0.092	0.101
			1	0.9	0.091	0.080	0.088	0.081
			0.9	0.9	0.100	0.080	0.090	0.082
119.7	0.03	0	1	1	0.027	0.028	0.029	0.029
			0.9	1	0.028	0.028	0.029	0.030
			1	0.9	0.029	0.027	0.029	0.029
			0.9	0.9	0.028	0.029	0.030	0.029
119.7	0.1	0	1	1	0.030	0.029	0.031	0.031
			0.9	1	0.029	0.028	0.031	0.029
			1	0.9	0.028	0.029	0.030	0.033
			0.9	0.9	0.027	0.029	0.031	0.030
119.7	0.3	0	1	1	0.051	0.052	0.051	0.049
			0.9	1	0.044	0.042	0.052	0.052
			1	0.9	0.048	0.053	0.056	0.051
			0.9	0.9	0.056	0.053	0.050	0.052

According to the analysis, dispersion values increase substantially when the forward bourrelet diameter standard deviation exceeds 0.4 mm. For the values of standard deviation between 0-0.4 mm there is a small difference in the dispersion. The dispersion is not affected much until the deviation value reaches to 0.4 mm. In addition, it is observed from the results that, for the considered two forward bourrelet diameters, for small values of standard deviation in forward bourrelet, the dispersion is higher for 119.5 mm diameter but as the standard deviation increases, then the dispersion becomes higher for 119.7 mm diameter.

When the results as given in Tables 3 and 4 are compared, it is obvious that the changes in muzzle velocity have no effect on the dispersion in horizontal direction as expected but the changes in muzzle velocity increase the dispersion in vertical direction significantly with almost similar rate.

In the final analysis, the effects of the runout of forward and rear bourrelet are investigated using nominal gun support and recoil stiffness values and nominal muzzle velocity value. For one forward bourrelet value (119.7 mm), and different forward bourrelet standard deviation values (0.03 mm-0.5 mm), the results are as given in Table 5.

The results show that, the increase in the runout of rear bourrelet from 0 to 0.2 mm does not influence the dispersion at a noticeable degree. It is also observed that, the forward bourrelet runout of 0.2 mm has no visible effect on the dispersion for two calibre guns in either axis compared to the dispersion values as given in Table 3.

It is observed that the decrease in projectile/bore clearance (forward bourrelet diameter) resulted in improved dispersion of ammunition. For 119.7 mm forward bourrelet diameter and 0.03 mm of standard deviation, minimum dispersion is obtained. It is shown that when the clearance between the sabot and gun bore is high and its standard deviation is above 0.4 mm, then the dispersion increases considerably in both L44 and L55 calibre guns. The dispersion value is three times higher for forward bourrelet diameter of 119.5 mm and its standard deviation of 0.5 mm, compared to the configuration of forward bourrelet diameter of 119.7 mm and its standard deviation of 0.03 mm or 0.1 mm.

The initial misalignment of the projectile within the gun tube due to manufacturing tolerances produces secondary forces causing transverse displacement and yawing motion of the projectile as it travels from breech to muzzle. This motion

Table 2. Dispersion analysis results due to muzzle velocity, stiffness and forward bourrelet diameter changes.

Forward bourrelet diameter (mm)	Forward bourrelet std dev (mm)	MV Std dev (m/s)	Recoil Stiffness ratio	Vertical stiffness ratio	Dispersion			
					L55		L44	
					Horizontal (mils)	Vertical (mils)	Horizontal (mils)	Vertical (mils)
119.5	0.1	10	1	1	0.046	0.095	0.049	0.105
			0.9	1	0.043	0.093	0.047	0.105
			1	0.9	0.049	0.096	0.048	0.105
			0.9	0.9	0.046	0.095	0.050	0.105
119.5	0.3	10	1	1	0.054	0.100	0.056	0.110
			0.9	1	0.058	0.099	0.058	0.108
			1	0.9	0.058	0.098	0.059	0.108
			0.9	0.9	0.058	0.100	0.055	0.109
119.5	0.5	10	1	1	0.083	0.116	0.096	0.129
			0.9	1	0.083	0.129	0.082	0.129
			1	0.9	0.076	0.118	0.093	0.120
			0.9	0.9	0.076	0.113	0.093	0.138
119.7	0.03	10	1	1	0.030	0.087	0.028	0.097
			0.9	1	0.030	0.088	0.030	0.097
			1	0.9	0.028	0.088	0.029	0.097
			0.9	0.9	0.026	0.087	0.028	0.097
119.7	0.1	10	1	1	0.030	0.088	0.032	0.097
			0.9	1	0.027	0.088	0.033	0.098
			1	0.9	0.029	0.087	0.030	0.097
			0.9	0.9	0.031	0.088	0.028	0.097
119.7	0.3	10	1	1	0.049	0.099	0.053	0.106
			0.9	1	0.053	0.098	0.055	0.110
			1	0.9	0.047	0.100	0.047	0.103
			0.9	0.9	0.051	0.099	0.053	0.106

Table 3. The change of dispersion due to forward bourrelet diameter changes.

Forward bourrelet diameter (mm)	MV Std dev (m/s)	Recoil stiffness ratio	Vertical stiffness ratio	Forward bourrelet std dev (mm)	Dispersion			
					L44		L55	
					Horizontal (mils)	Vertical (mils)	Horizontal (mils)	Vertical (mils)
119.5	0	1	1	0.03	0.048	0.047	0.044	0.047
				0.1	0.051	0.046	0.045	0.046
				0.25	0.051	0.054	0.050	0.050
				0.4	0.068	0.068	0.061	0.071
				0.5	0.077	0.087	0.073	0.082
119.7	0	1	1	0.03	0.029	0.029	0.029	0.029
				0.1	0.032	0.031	0.031	0.028
				0.25	0.048	0.040	0.044	0.039
				0.4	0.073	0.069	0.083	0.069
				0.5	0.102	0.108	0.109	0.107

Table 4. The change of dispersion due to forward bourrelet values with muzzle velocity changes.

Forward bourrelet diameter (mm)	MV Std dev (m/s)	Recoil stiffness ratio	Vertical stiffness ratio	Forward bourrelet std dev (mm)	Dispersion			
					L44		L55	
					Horizontal (mils)	Vertical (mils)	Horizontal (mils)	Vertical (mils)
119.5	10	1	1	0.03	0.046	0.104	0.045	0.095
				0.1	0.049	0.105	0.046	0.095
				0.25	0.049	0.106	0.051	0.094
				0.4	0.074	0.114	0.066	0.103
				0.5	0.096	0.129	0.083	0.116
119.5	20	1	1	0.03	0.052	0.191	0.046	0.171
				0.1	0.048	0.191	0.047	0.172
				0.25	0.057	0.192	0.049	0.174
				0.4	0.071	0.197	0.070	0.181
				0.5	0.082	0.201	0.079	0.186
119.7	10	1	1	0.03	0.028	0.097	0.030	0.087
				0.1	0.032	0.097	0.028	0.088
				0.25	0.045	0.101	0.045	0.097
				0.4	0.076	0.119	0.089	0.111
				0.5	0.085	0.145	0.096	0.128
119.7	20	1	1	0.03	0.029	0.187	0.027	0.169
				0.1	0.030	0.187	0.028	0.168
				0.25	0.041	0.188	0.044	0.172
				0.4	0.064	0.188	0.074	0.182
				0.5	0.087	0.210	0.113	0.197

Table 5. The change of dispersion due to forward and rear bourrelet runout.

Forward bourrelet diameter (mm)	Forward bourrelet std dev (mm)	Forward bourrelet runout (mm)	Rear bourrelet runout (mm)	Dispersion			
				L44		L55	
				Horizontal (mils)	Vertical (mils)	Horizontal (mils)	Vertical (mils)
119.7	0.03	0.15	0	0.038	0.037	0.035	0.033
	0.1			0.037	0.037	0.034	0.036
	0.25			0.046	0.048	0.044	0.046
	0.4			0.074	0.076	0.077	0.073
	0.5			0.090	0.107	0.097	0.092
119.7	0.03	0.15	0.1	0.040	0.040	0.037	0.035
	0.1			0.044	0.043	0.034	0.036
	0.25			0.050	0.051	0.050	0.049
	0.4			0.075	0.077	0.075	0.070
	0.5			0.109	0.103	0.111	0.118
119.7	0.03	0.15	0.15	0.045	0.043	0.039	0.040
	0.1			0.045	0.047	0.040	0.039
	0.25			0.050	0.055	0.048	0.050
	0.4			0.080	0.082	0.073	0.075
	0.5			0.087	0.104	0.097	0.107
119.7	0.03	0.15	0.20	0.045	0.043	0.041	0.043
	0.1			0.046	0.047	0.042	0.039
	0.25			0.059	0.059	0.051	0.052
	0.4			0.085	0.092	0.082	0.073
	0.5			0.113	0.108	0.093	0.109

affects the muzzle exit conditions (yaw angle, angular rate and transverse velocity). As the gap between the bourrelet and bore inner diameter is higher, then the amplitude of the yaw motion increases and the changes in the muzzle exit conditions also increase.

Although the dispersion values obtained according to the configurations are nearly the same for both L44 and L55 guns, however the dispersion is slightly higher in L44 calibre gun. The slight difference in dispersion may be due to the differences in muzzle velocities (due to the length of the barrels) and muzzle exit conditions (muzzle exit yaw, yaw rate, transverse velocity) because of the elastic deformation of the barrel during the projectile motion inside the bore. Both L44 and L55 calibre guns deform elastically in different shapes and this effect causes different the muzzle end motions.

Furthermore, the results of the analyses indicate that the 10% changes in the nominal recoil and the vertical stiffness values have negligible effects on the dispersion.

The analysis shows that muzzle velocity variations influence the dispersion in vertical direction substantially compared to horizontal direction in both calibre guns. This is because the muzzle velocity changes affect the travelling range and deceleration characteristics of the projectile and this causes dispersion in elevation direction. Therefore, muzzle velocity changes should be controlled for better gun shooting performance.

Moreover, the increase in runout of rear bourrelet from 0 to 0.2 mm does not influence the dispersion at a noticeable degree. Due to the computation, the forward bourrelet runout (0.2 mm) has no visible effect on the dispersion for two calibre guns.

Although it is not directly possible to compare the results of this study with the previous studies because of the differences in the gun and projectile models and the parameter variations, however the trend and the order of magnitude of the dispersion are in good agreement. The increase in clearance between the projectile bourrelet and gun bore, increase in muzzle velocity variations and the decrease in the stiffness of the gun/projectile system increases the dispersion as stated in referred studies.

4. CONCLUSIONS

The effects of the changes in projectile muzzle velocity, forward and rear bourrelet diameter, manufacturing tolerances, gun support stiffness and recoil stiffness on the dispersion of target impact points are investigated both separately and in combination. Statistical dispersion analyses including interior ballistic, In-bore balloting and exterior ballistic analyses are conducted using PRODAS ballistic software. Both projectile and gun are modelled as flexible bodies. Interior ballistic analysis is conducted in order to determine the time dependent forcing function. In-bore balloting analysis is performed to determine the projectile exit state conditions required as initial conditions to run free-flight 6 dof trajectory analysis. For the statistical dispersion analysis in PRODAS, the projectile is initially randomly oriented within the gun tube due to manufacturing tolerances.

The procedure applied in this study is both effective and provides useful insight for the designers to assess the gun and/or projectile parameters needed to be changed to minimise the dispersion in the early stages of the design. Following this method, minimum and maximum clearance conditions can be analysed and most suitable tolerances can be determined easily considering both the gun system performance and manufacturability and therefore both cost effective and optimised solutions can be achieved.

To investigate the effects of whole weapon systems parameters on the target impact dispersion including every important gun and projectile components in the analysis without any simplifications, complicated three dimensional finite element modelling is required. However, this sort of analysis requires explicit finite element solvers to simulate the projectile-gun interaction and projectile launching event with a high power computing hardware.

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CONTRIBUTOR

Dr Tolga Dursun obtained BSc and MSc degrees from the Mechanical Engineering Department of Middle East Technical University and PhD from the Mechanical Engineering Department of Gazi University, in 2006. Currently working as a senior lead design engineer for ASELSAN Inc Microelectronics, Guidance and Electro-Optics Division. He is responsible for designing, analysing and testing of electro-mechanical systems for military platforms. His research areas include: finite element analysis, gun dynamics, ballistics and vibration and shock analysis of structures.

He has contributed in reviewing the related literature, building the gun dynamics model, performing the analyses and writing the manuscript.