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R.A.R.D.E. MEMORANDUM 19/69

Jump in Tank Guns (R)

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Loughborough University of Technology attached to B2 Branch)

Fort Halstead.
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August 1969

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J.R. Mitchell, B.Sc.(Eng.), D.L.C.
(Loughborough University of Technology attached to B2 Branch)

Summary

A report of work carried out during a Vacation Consultancy at R.A.R.D.E. in the Autumn of 1968. Possible origins of Gun Jump are considered together with suggested means of its reduction.

Approved for issue:

F.H. Seeley, Principal Superintedent, 'B' Division

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1. INTRODUCTION

A total period of some four weeks during the months of August and September 1968 was spent at B2 (Ballistics) Branch at Woolwich under Mr. G.R. Nice, Branch Superintendent.

A review of the extensive literature relating to the problem of gun jump was made, covering work by both British and American authorities since the second world war. This included the work of the S.A.C. Gun Jump Panel, operational between the years 1951-57, although this considered primarily mountings other than those in tanks. Library facilities at Fort Halstead were utilised to obtain as comprehensive a literature survey as possible. A bibliography of pertinent reports was compiled and is appended to this memorandum.

Visits were made to three other locations during the course of the consultancy:

(i) B1 (Guns) Branch at Fort Halstead to discuss design features of both the barrel and its mounting within the vehicle.

(ii) F.V.R.D.E., Chobham where discussions were held with Mr. C.J. Weiland, Superintendent Weapon Trials, on the practical aspects of jump and its measurement in the field, and Dr. G.N. Harvey, Assistant Director of Research and Mr. Hunt on recent developments in the mounting of the gun within the tank.

(iii) R.A.C. Gunnery School, Bovington Camp, Wareham to observe firings from Centurion and Chieftain tanks under service conditions and to discuss the implications of jump from the gunners point of view.

2. ORIGINS OF GUN JUMP

The term jump is technically associated with the angular deviation in the vertical plane between the undisturbed muzzle axis and the initial line of flight of the projectile. In practice, similar effects may be observed in the horizontal plane, though usually of lower magnitude, and are referred to as throw off or lateral jump. These two measurements are simply the vertical and horizontal components of the total vectorial deviation of the projectile from its intended flight path and it would be wrong to suppose that these are necessarily partially or completely independent. The term jump in this memorandum is used to indicate the total effect and includes those factors contributing to the deviation, in any direction, between the line of flight of the projectile and the undisturbed muzzle axis up to and including the immediate post ejection period.

The literature on the subject is very extensive, covering many years of research, and numerous reasons for gun jump have been proposed. An analysis of the reported work indicates that there are three broad effects within the system from which the phenomena of gun jump has its origins. These are by no means

mutually exclusive and are in fact almost certain to interact extensively in such a system. The jump in any given situation is therefore made up of components basically arising from different effects but coupled in some fairly complex manner. The three effects are:-

(i) motions of the barrel during shot travel and particuarly at the time during which the projectile is emerging from the muzzle,

(ii) a lack of constraint or location of the projectile within the bore of the barrel or other factors permitting relative motion between the shot and the barrel to develop,

(iii) post ejection forces and moments which act on the projectile immediately after its emergence from the muzzle of the gun.

Of the factors contributing to these effects, some clearly will be primarily random in nature thus causing a dispersion about an MPI while others will have a regular bias content leading to an MPI which differs from the point of aim.

The factors causing jump are primarily a function of the particular gun/ammunition combination and may vary widely between different weapon systems and even for the same gun firing different ammunition.

2.1 Motions of the barrel

If, during the time of shot travel, the barrel is in motion such that at the time of shot ejection the muzzle axis has undergone some transverse or angular displacement from its undisturbed position or alternatively the muzzle possesses transverse or angular components of motion at the time of shot ejection, then the line of flight of the projectile will clearly be directly affected. Some components of such motions may produce indirect effects in that they result in the emergence from the muzzle of a yawing projectile. These latter effects are dealt with in section 2.3.

Simple transverse and angular displacements of the muzzle at shot ejection will give direct deviations from the intended line of flight along the actual muzzle axis at this instant. The transverse displacement will have a negligible effect even for very flexible barrels.

A transverse velocity of the muzzle will impart an equal component to the projectile resulting in a direct deviation from the undisturbed muzzle axis. Small velocities could produce significant effects. For a muzzle velocity of 4500 ft/sec, a transverse velocity of 1 ft/sec will produce a direct jump of 0.75 mins, while for a slower projectile of 2600 ft/sec the corresponding figure will be 1.3 mins. A transverse velocity will also produce an initial yaw of the projectile.

An angular velocity of the muzzle will not produce any direct effect, but will give rise to an initial rate of change of yaw.

If the muzzle possesses transverse and angular accelerations, then transverse forces will act on the projectile and during the time that the muzzle is being transversed by the shot, when certain constraints are removed, some relative angular motion between the shot and the barrel may develop leading to a yawing projectile.

Experimental evidence shows all these components to be present and moreover that there can be significant variation between successive firings of apparently identical ammunition from the same gun under the same conditions.

The primary causes of barrel motions may be classified as follows:-

2.1.1 Shot/barrel interaction

(i) transverse forces generated by eccentric shot riding up the bore. This eccentricity may be attributable to static or dynamic unbalance of the shot or may be produced by malengraving of the driving band,

(ii) transverse forces resulting from a projectile riding in a bent or sagging barrel,

(iii) conditions at shot start which may lead to a non-uniform engagement of the driving band with the rifling,

(iv) The torque reaction of a projectile on a bent barrel causing transverse deflections.

2.1.2 Mounting arrangements

(i) recoil action in which any longitudinal forces acting on the barrel (gas forces, recuperator, slides etc.) are asymmetrical with respect to the barrel axis through its mass centre,

(ii) impulsive angular motion of the breech end of the barrel produced by the sudden expansion of the barrel in the clearance of the supporting bushes in the cradle,

(iii) backlash effects in the elevating or transverse gear,

(iv) rotation of the barrel about the single anti-rotation key will cause transverse motion of the breech end of the gun.

2.1.3 Recoil of a bent gun

Some of the effects mentioned in 2.1.1 to 2.1.3 originate at the breech end of the barrel. In order to affect conditions at the muzzle therefore, they must propogate to reach the muzzle before the shot does so. Axial wave velocities in steel are about 16000 ft/sec, while transverse wave velocities of between 4000-9000 ft/sec have been measured experimentally. These velocities would adequately allow the disturbances to reach the muzzle in time.

2.2 Relative motion between shot and barrel

When relative motion occurs between shot and barrel, apart from directly along the axis of the gun, the axis of the projectile is no longer constrained to the required direction and the projectile will generally emerge from the muzzle with an initial yaw and rate of yaw. Furthermore, since under these conditions the shot is forced to spin about an axis other than its principal longitudinal axis, rotation of the shot about its base in a plane containing the shot axis may well occur as the projectile emerges.

The primary causes of relative motion between the projectile and the bore are as follows:-

2.2.1 Radial clearance between the shot and the barrel which may be effectively increased by engraving of the nose of the shot.

2.2.2 Malengraving of the driving bands.

2.3 Post ejection effects

The projectile emerges from the muzzle to be overtaken by a high velocity turbulent gas cloud. The aerodynamic situation in this regime is far from favourable since the shot is effectively flying backwards relative to the enveloping gases. Some experimental evidence suggests that the projectile continues to accelerate for a short time after emergence from the muzzle, indicating that it is subject to significant forces in this period.

Any yaw or rate of yaw present as the shot leaves the muzzle resulting from effects outlined in 2.1 or 2.2 will give rise to aerodynamic forces and moments acting on the shot which will disturb its line of flight from that initially adopted at ejection. There may also be shock wave effects as the shot passes through the wave front of the gas cloud. Any transverse or angular accelerations of the muzzle present at ejection will cause a cross flow component of the muzzle gases relative to the shot, producing further aerodynamic disturbance.

Gyroscopic effects will also exist, but while these may have an integrated effect down the full trajectory of the projectile, they are unlikely to significantly effect the trajectory in this immediate post ejection period.

3. SYSTEM ASYMMETRY

The phenomena of gun jump is basically an asymmetric behaviour and an examination of the factors involved in giving rise to jump indicate that asymmetry of the weapon system, produced in various ways, is a major cause. Identification of important asymmetric effects allows the root causes of certain jump components to be ascertained.

Asymmetry is present within the system under four main headings and an attempt to identify important factors leads to the following classification. The presence of any one or more of these factors in a given weapon system could well lead to jump being experienced.

3.1 Asymmetry of gun and mounting

3.1.1 mass centre of barrel relative to geometric longitudinal axis.,

3.1.2 disposition of recoil system with respect to gun axis,

3.1.3 clearance of cradle bushes,

3.1.4 anti-rotation key location,

3.1.5 bent barrel.

3.2 Asymmetry of shot and barrel

3.2.1 static or dynamic unbalance of shot,

3.2.2 malengraving of driving bands,

3.2.3 shot start conditions,

3.2.4 yaw in bore as a result of clearance.

3.3 Asymmetry of shot and muzzle gas cloud

3.3.1 emergence of yawing projectile,

3.3.2 transverse velocity of muzzle,

3.3.3 transverse or angular accelerations of muzzle.

3.4 Asymmetry of in-flight separation

3.4.1 separation from sabot and petals, for APDS,

3.4.2 shedding of driving bands.

4. RECOMMENDATIONS

Efforts directed at the reduction of asymmetry in all parts of the gun/projectile system should result directly or indirectly in a reduction of both the random and the regular bias content of jump and its total sense. The return in some cases however may well be undetectable.

It is difficult to accurately specify those areas which would bring significant improvements, but the following factors appear to be worthy of further investigation.

4.1 Method of support of barrel in cradle

Work currently in hand at F.V.R.D.E., Chobham on a method which obviates the need for cradle bush clearances to take up radial barrel expansion on firing, has already indicated that significant reductions in both the random and regular bias components of jump can be achieved. This is almost certainly due to the removal of the angular impulse given to the breech end on firing with the existing method of support. (Current support bushes on the 105 mm and 120 mm guns allow rigid body rotations of the barrel of about 2.5 mins).

4.2 Location of the anti-rotation key

The use of a single anti-rotation key located some way from the principal longitudinal axis of the barrel, leads to a substantial unbalanced force acting to resist rotation and this will give rise to transverse motions of the breech. Anti-rotation keys should be symmetrically disposed about the principal axis to produce a balanced force system or some alternative system employed leading to a pure torque acting on the barrel. An unbalanced force system would be acceptable provided that the effects of this do not act before shot ejection. One such solution would be to allow the barrel angular recoil in addition to axial recoil.

4.3 Elevation and transverse gear effects

It is a service requirement that guns should be brought on to battery from preferred directions, dependent on the characteristics of the gun, otherwise increased dispersion results. This would point to clearance effects in the elevating and transversing gears.

4.4 Static dynamic unbalance of shot

Reported theoretical work has indicated that relatively small eccentricities (0.010") are capable of producing significant jump figures (2.5 mins) due to the muzzle motions produced by the forces of interaction between the shot and the barrel.

4.5 Development of yaw in bore

A reduction of the relative transverse or angular motion between the shot and the barrel will correspondingly reduce the unbalanced aerodynamic forces and moments caused by the passage of a yawing projectile through the muzzle gas cloud.

4.6 In-flight separation

Forces and moments, probably aerodynamic in origin, acting on the shot at separation from its sabot in the case of APDS on the break up of driving bands, could be significant.

APPENDIX 1

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