THE BALLISTIC MYSTERY OF 'PARIS GUN'

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Abstract 'Paris Gun' (Pariskanone) is a famous armour in the World War I. A brief description of the Paris Gun is given. Based on the restored aerodynamic property of the gun projectile, a set of the ballistic results are reported in this article. Several trajectory prediction models like 4-DOF, 5-DOF, 6-DOF etc. are used. It is verified via Paris Gun that the 5D model is a good compromise between 4D and 6D models when calculating high elevation and long range trajectory of spin-stabilized projectiles. The ballistic prediction program D456R6 is introduced briefly.

Keywords paris gun, exterior ballistics, ballistic stability, trajectory prediction model, model reduction

The Paris Gun was designed by a team of Krupp engineers led by Prof Kausenberger. It has three mountings and several barrels. The first use of Paris Gun was to bombard Paris on 23 March 1918. The bombardment continued intermittently until 7 August 1918. Totally 203 shells were fired and the majority hit the city.

The Paris Gun was erroneously called Big Bertha by Allied soldiers in World War I. It may be the best-known and the most mysterious gun of all time. There are few who do not know the story of the bombardment of Paris at a distance of 79 miles from a point 10 miles behind the German lines in the St. Gobain Wood near Loan. Also, there are few who know anything about the gun which achieved such an incredible feat.

Allied efforts in detecting the guns succeeded in determining their general location despite elaborate efforts to conceal them. Aerial bombardment and long-range shelling of the St. Gobain Wood by French railway guns were of no avail, however. Eventually, the mountings with no barrels, which were never found, fell into Allied hands and the shelling of Paris was halted.

As for the true purpose of the Paris Gun, we shall probably never know. Some speculated that the Germans used it as a terror weapon, hoping to break the morale of the French people. Others felt that its function was to cause people to flee Paris and in doing so disrupt the roads and railways.

This article tries to give a general look of Paris Gun. The ballistic prediction program

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D456R6 is introduced briefly. The central task of this article is to demonstrate the interesting ballistic behavior of Paris Gun which is described in detail. One of the purposes is to make a fair comparison of several trajectory prediction models like 4-DOF, 5-DOF, 6-DOF etc. and to verify that the 5D model is a good compromise between 4D and 6D models when calculating high elevation and long range trajectory of spin-stabilized projectiles.

1 CONFIGURATION OF PARIS GUN

The overall configuration of Paris Gun is described in Figure 1. The basic specifications are given in Table 1. Where d is calibre of gun; X_{max} is the maximum range; L_1 is length of barrel; L_2 is length of recoil; θ is elevation; j is traverse; M is mass of gun; v_0 is muzzle velocity; r is rate of firing.

Table 1 Specifications of Paris Gun

d/mm	X_{max}/km	L_1/m	L_2/m	θ/(°)	j/(°)	M/t	v_0/m·s^{-1}	r/h^{-1}
210/240	131.9626	3.302	0.1778	+54	360	142	1609.3	6

Note that the barrel is braced by a suspension system. See Figures 1. This was necessary because of the great length and weight of the barrel, which vibrated for two minutes after each firing. It is interesting to note that many long-barrelled, large-calibre guns have a barely perceptible 'droop' in the barrel and this will straighten out on firing momentarily.

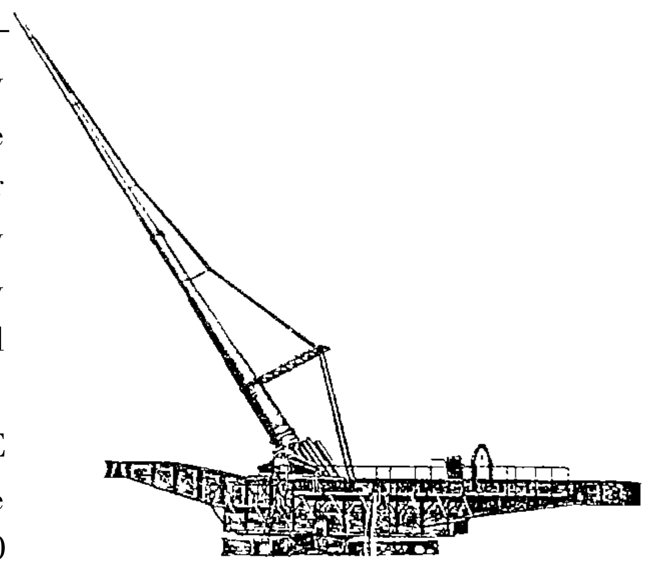

Figure 1 Paris Gun-Configuration

The shell of Paris Gun was a 210 mm HE with copper driving bands. See Figure 2. The life of each inner gun tube was thought to be 60 rounds, so 60 numbered shells, each a little large in calibre than the one preceding it, were provided for each barrel and fired in sequence. The calibre in round no. 60 was 222 mm. The weight of the propellant also varied with each shot.

2 EXTERIOR BALLISTICS PREDICTION

2.1 A Brief Review

As we know, the first computer was made mainly for the ballistic prediction in Ballistic

Research Laboratory(BRL), Aberdeen, USA. Exterior ballistic prediction has been the focus of research since last century. Due to the limitations of computing ability, early results were mainly obtained by analytical method based on some reasonable yet mathematically clever approximations. C. H. Murphy pioneered such kind of work since 1960s[1]. Some quantitative insights can be gained by the modified point mass (MPM) ballistic prediction model[2] which is referred to as the 4-DOF model where the yaw of repose constitutes another DOF in addition to the conventional 3-DOFs in the point mass model. G. V. Bull pioneered the gun launched missile research[3] possibly motivated by the Paris Gun using the analysis tools developed in [1]. Program LOB[4] and the later version LOBS[5] are excellent implementations of the model of [1, 2]. Considering the computing power, a rigid body model is possibly realistic and a program LOB6[6] was developed based on LOBS which can be used as a benchmark program to check the accuracy of 4DOF ballistic prediction.

Based on the above work, extensive ballistic calculations were made by this author and some observations led to the birth of the idea of 5DOF model which is a compromised model between 4DOF and 6DOF model. As we know, the major source of ballistic prediction errors is the inaccurate prediction of the movement of angle of attack. Clearly, a rigid 6-DOF (R6D) model can be used to accurately predict the angle of attack history such that an accurate prediction of range and deflection can be achieved. However, due to the coupling of the fast arm (mode) and slow arm (mode) in the the angular movement, a very small integration step has to be used which restricts the wide use of R6D in applications like firing table generation. It is most often used in the investigation of the effects of initial disturbances. There is indeed a need, even today, of a compromised model for ballistic prediction. As analyzed in [10], the yaw of repose in 4DOF is essentially a steady state solution of the motion of angular movement. Therefore, neglecting the fast arm will give a compromised model which is called 5DOF model. The basic idea is so simple to any researcher in the field of control engineering which actually retains dominating poles of the system.

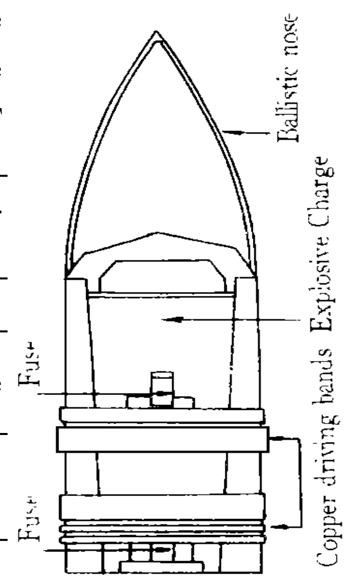

Figure 2　Paris Gun-Shell

When starting from the point mass 6DOF model[1], a modified 6DOF model (6Dm) can be obtained using the modified prediction method for angle of attack based on the use of a special co-ordinate system, i. e., the total angle of attack body co-ordinate system (TABCS) and the total angle of attack wind-velocity co-ordinate system. It has been demonstrated that under the newly established co-ordinate system, a better prediction result can be achieved. Detailed descriptions can be found in [8]. Then, applying the basic idea discussed above, a 5DOF model and a modified 5DOF model (5Dm, based on 6Dm) can be derived[8]. However, 6D is still a point mass model. Therefore, starting from R6D, similarly, R5D can be obtained which is discussed in detail in [11]. Moreover, starting from the detailized 6D model, a new 4D model has been obtained which is similar to that used in LOBS but more factors have been taken into consideration in the new 4D model[10]. In particular, the speed of the new 4D model is 40% faster than that of LOBS.

So far, seven models have been introduced, i.e., 4D, 6D, 6Dm, 5D, 5Dm, R6D and R5D. It is possible to switch between them[7]. The autoswitching is particularly efficient when predicting disturbed trajectories. At the beginning, since the high frequency mode has been activated, 6D, 6Dm or R6D should be used to accurately predicte the angular motion. For spin-stabilized projectile, it is often the case that the fast arm will die out shortly and then, 5D, 5Dm or R5D could be used to save computing cost. When the maximal angle of attack is small, say, less than 10 degrees, then, 4D can also be used to give a reasonably precise result.

2.2 Programs LOBS and D456R6

Program LOBS[5] was developed by Space Research Corporation (SRC). It is a commercial software written in Fortran 77. Based on the main frames of LOBS, a new package D456R6 was developed by the author where the common modules like atmosphere, gravity, based bleed, rocket thrust, integrator as well as integration even handling are re-used. The input format is also the same. In fact, only the right-hand-side function (RHSF) has been changed to include all the ballistic models mentioned above (4D, 6D, 6Dm, 5D, 5Dm, R6D and R5D) as well as the model switching which is controlled by parameter ISG in the input file. Table 2 gives a summary of implemented models or model switches.

Table 2 Summary of ballistic prediction models in D456R6

ISG	model and description
−3	R6D-4D switching
−2	R6D-R5D switching
−1	R6D only
0	4D(fast, calculate SG-gyroscopic stability factor)
1	4D(fast, on SG)
2	4D(fast, calculate yaw drag due to initial disturbance)
3	5D-5Dm(extra integration of yaw of repose)
4	5D(integrate yaw of repose, calculate yaw drag due to initial disturbance)
5	6D-6Dm switching
6	5D only
7	5Dm only
8	6D only
9	6Dm only
10	6Dm-5Dm switching
11	6Dm-4D switching

Program D456R6 run at either batch mode or conversational mode. It permits operation of the program in the following modes:

- IMET= 1 standard trajectory;
- IMET= 2 MET data reduction;
- IMET= 3 direct fire data reduction;
- IMET= 4 dispersion analysis;
- IMET= 5 real atmosphere trajectories.

Nominal trajectories are to be computed using various ballistic models. For IMET= 2, actual meteorologic data in standard format can be read in and be reduced to provide relevant parameters used in trajectory prediction. The purpose of MET data reduction is for either range fitting by zero-lift drag (FITCD= 1) or range fitting by ballistic coefficient (FITCD= 2). In this way, the real flight situations can be accommodated. Moreover, in IMET= 2, deflection fitting can also be included. For IMET= 3, it reduces direct fire range data to standard conditions. It matches measured conditions for terminal range, height and time or velocity by adjusting the initial quadrant elevation (QE) and the drag form factor. For IMET= 4, sensitivity factors for unit changes in parameters like roll moment (percent), range wind, cross wind, density (percent), temperature (percent), velocity, maximal angle of attack (yaw drag component, degrees), roll damping, center of gravity and QE (mils) can be obtained. There are three subtasks in this case, i. e., sensitivity analysis for nominal trajectory with matched range, sensitivity analysis for nominal trajectory at a fixed QE, and nominal trajectory only (match range). Finally, IMET= 5 sets the flight through a real atmosphere, i. e., interpolating from the MET data.

It is important that the results obtained by using different ballistic models have comparability because only the RHSF is different. This is particularly useful in evaluating various developments in ballistic prediction models.

In what follows, we will run D456R6 for Paris Gun. On one hand, results from various models are compared to illustrate the proposed 5D model. On the other hand, some special characteristics of Paris Gun are to be revealed.

3 BALLISTIC PREDICTION RESULTS FOR PARIS GUN

3.1 Nominal Trajectories

First, nominal trajectories are computed by R6D which are the standard results for comparison with the results from using other models. Three QE′s are considered: 46°, 50° and 54°. The muzzle velocity is fixed at V_0= 1646 m/s. Table 3 summarizes the R6D results for the above three cases. Where θ_0 is QE; T is total time; X is rang; Z is deflection; W_{max} is maximum yaw; v_c is final velocity; θ_c is final angle. Figure 3 is the total angle of attack histories along the trajectories. While the rang~ height and range~ deflection plots are given in Figure 4.

Table 3 Summary of nominal ballistic prediction results of Paris Gun using R6D

θ_0/(°)	T /s	X /m	Z/m	W_{max} /(°)	v_c /m·s^{-1}	θ_c /(°)
46	175.63	124951	4848.7	16.68	389.9	53.91
50	193.01	128470	6062.0	32.89	338.6	58.76
54	210.17	128687	6783.9	50.56	279.2	63.66

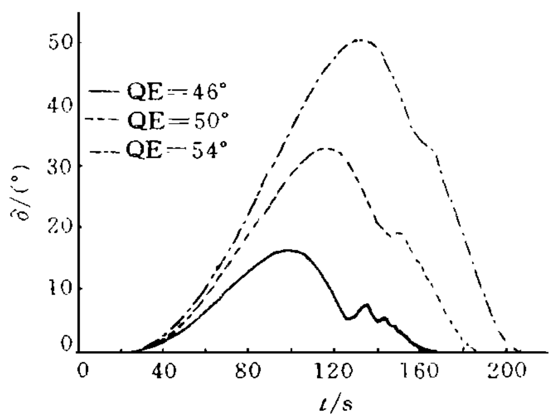

Figure 3 Total angle of attack of nominal trajectories

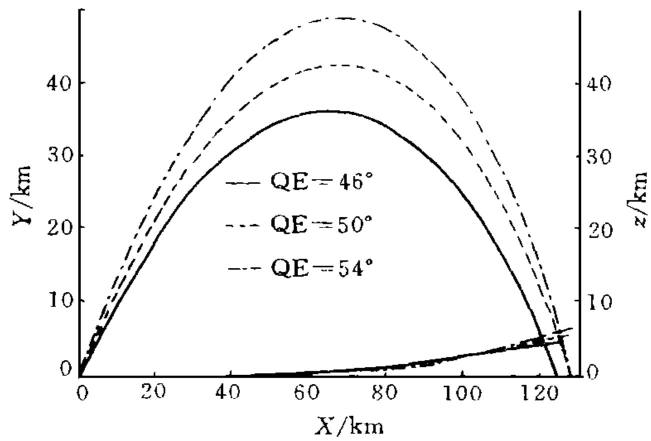

Figure 4 Range~ height and range~ deflection plot of nominal trajectories

3.2 Disturbed Trajectories

We only consider the case of QE= 50° and V_0= 1646 m/s for simplicity of presentation. When introduced with an initial angle of attack as T= 2° and U= 2°, the Paris Gun exhibits some interesting behaviors in the ballistic response. In this case, complex and large motion of angle of attack at the initial part of the trajectory will induce larger drag which in turn will reduce the range. Meanwhile, the resultant drift will increase, too. This can be confirmed from the disturbed trajectory prediction results summarized in Table 4.

Table 4 Summary of disturbed ballistic prediction results of Paris Gun using R6D

θ_0/(°)	T /s	X /m	Z/m	W_{max} /(°)	v_c /m·s^{-1}	θ_c /(°)
46	173.67	122259	4905.3	15.59	386.0	53.95
50	190.75	125803	6155.5	31.44	338.4	58.66
54	207.83	126019	6966.6	49.11	278.6	63.63

3.3 Result Comparisons of Various Ballistic Prediction Models

Model autoswitching (ISG= − 2, − 3, 10, 11) is a very powerful method to precisely predict the ballistic variables with less efforts which is particularly useful in fast, accurate prediction of disturbed trajectory. Due to the space limitation, here, only nominal trajectory calculations with various ballistic models are considered. Set $V_0 = 1646$ m/s, $\theta_0 = 50^\circ$. Outputs during ballistic computation are turned off to get a fair computational time comparison. Results of six ballistic models are summarized in Table 5 for a clear comparison. As highlighted in Table 5, it is obvious that, 5Dm is a best compromise model between 4D and R6D. Essentially, this can be explained by comparing the T- U plots of various model.

Table 5 Summary of nominal ballistic prediction results of Paris Gun using various ballistic models

ISG	CPU time/s	X/m	Z/m	W_{max}/(°)	θ_c/(°)
-1	76.56	128470	6062	32.89	58.76
0, 1, 2	0.27	129718	6295.5	25.71	55.63
6	0.82	128247	6368.9	33.85	59.00
7	0.82	128351	6060.8	32.86	58.73
8	45.75	128351	6315.8	34.35	59.03
9	49.26	128524	5855.7	32.71	58.59

It is clear that 5Dm has been able to predict the angle of attack motion as precise as R6D. No difference between 5Dm and R6D can be seen from the results. In this case, the relative range error is (131962.6- 128470)/131962.6 < 2.65%. For other models like 6D, 5D etc., their prediction of the angle of attack motion is not as satisfactory as 5Dm. For detailed derivations and mathematical explanations, refer to [6- 11].

5 CONCLUDING REMARKS

In this article, we have presented, for the first time, some mystery aspects of the exterior ballistics of Paris Gun. A brief description of the Paris Gun(Pariskanone), is also given. Based on the aerodynamic property of the restored gun projectile, a set of the ballistic results are reported in this article. Some observations are made to comment the results obtained. Several trajectory prediction models like 4-DOF, 5-DOF, 6-DOF etc. are briefly introduced. It has been verified that the 5D model is a good compromise between 4D and 6D models when calculating high elevation and long range trajectory of spin-stabilized projectiles. The ballistic prediction program D456R6 is introduced briefly.

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巴黎炮的弹道秘密

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摘要 “巴黎炮”是第一次世界大战中使用过的著名火炮,简述了巴黎炮性能指标,基于反求火炮弹丸气动特性,给出弹道结果.使用了4自由度、5自由度和6自由度等几种弹道模型,通过巴黎炮的计算,证实在计算高仰角远射程旋转稳定弹时,5自由度模型是较好的折衷方案,同时简述了D456R6弹道计算程序.

关键词 巴黎炮,外弹道,弹道稳定性,弹道计算模型,模型简化