Developing a Javelin Throw as a Computer Experiment Using Orthogonal Array Latin Hypercube Design

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***Abstract* —This study aimed at adapting Orthogonal Array Latin Hypercube Design (OALHD) with parameters' specification OA (25, 3) LHD to javelin throw as computer experiments. Javelin throw is one of the competitive events in many major athletic events as well as in the Olympic Games. It is a track and field event where the javelin, a spear about 2.5m (8 ft 2 in) in length is thrown. This study assumed ranges of values for the three important factors that determine how far a javelin travels such as the time of flight, launched angle and launched velocity. The OA (25, 3) LHD was adapted to the resulting values to guarantee optimality and this was confirmed by comparing the variances of the three factors with OALHD and without OALHD. The Javelin throw dataset with OALHD has the minimum variance. The one with OALHD also explore a large portion of the experimental region while in the case of javelin throw without OALHD, all the data are equidistantly sampled along the main diagonal of the design space and this will give a very poor sample. The design factors, without OALHD, are perfectly correlated and it becomes impossible to distinguish among the effects of the design factors. The scaled OALHD was used to develop a javelin throw computer experiment using the simulators for horizontal and vertical displacements and velocities as well as the resultant velocity. Further results showed that the distance achieved for the javelin throw peaked at the launched angle of 20.4°. This study concludes that OALHD can be used whenever interest is focused on performing either a traditional or computer experiment on real life situations.**

Keywords - *Computer experiment; Space-filling design; Orthogonal array latin hypercube design; Physical experiment; Javelin throw.*

I. INTRODUCTION

Computer experiments are becoming more commonly adopted in modern businesses, engineering and scientific applications due to their flexibility and wide applicability. A computer experiment is an experiment conducted using data obtained from a computer model in lieu of the physical process. The advancement in computer power has made it possible to perform experiments on simulators. The authors in [7] quoted [12] to have reported that the first computer experiment was conducted by Enrico Fermi and colleagues in Los Alamos in 1953.

The application of experimental design has traversed the field of agriculture as it is now used in modern businesses, science, engineering and technology. An experimental design is a series of tests in which purposeful changes are made to the input variables of a process and the effects on response variables are measured [13]. Experimental design is applicable to both physical processes and computer simulation models. It is an effective tool for maximizing the amount of information gained from a particular study while minimizing the amount of data to be collected. The classical experimental designs are used when physical experiments are performed [6] while space-filling designs have found its applications in computer experiments. Several authors have discussed different applications of computer experiments. Authors in [11] and [4] stated that computer simulation was used in the design of analog integrated circuit behaviour. The authors in [2] and [3] discussed the environmental experiment which shows applications of design and modelling techniques for computer experiments. Computer experiments are also used in the design of engine block and head joint sealing assembly containing multiple components [1].The author in [10] gave an application on designing a heat exchanger for a representative electronic cooling application. Other applications abound in the literature.

Space-filling designs are designs that spread points evenly throughout the experimental region. Popular space-filling designs that have been discussed in the literature include Latin Hypercube Designs (LHDs), Orthogonal Arrays (OAs), Distance Based Designs and Uniform Designs among others. The OA (49,3)LHD and OA(49, 8) LHD have also been proposed by[8] and [9] to develop a simple pendulum and borehole computer experiments.

An Orthogonal Array Latin Hypercube Design (OALHD) is coined in this study as a Latin hypercube design constructed based on orthogonal arrays in order to achieve better space-filling properties. The OA (25, 3) LHD constructed by [8] was adopted to develop a javelin throw computer experiment. A javelin throw is one of the applications of projectile motion in Physics and it has been reported that the launched velocity is the most important factor for the flying distance of the javelin [5]. This study considered the time of flight, launched angle and launched velocity to determine how far a javelin travels.

II. Materials and Methods

A computer program was written using a MATLAB programming language to develop a javelin throw computer experiment. The OA (25, 3) LHD was scaled according to the assumed ranges for javelin throw design variables as shown in Table1 using Equation 1.

$$y_{OALHD} = \frac{y_{data} - y_{datamin}}{y_{datamax} - y_{datamin}} \qquad (1)$$
$$y_{data} = y_{OALHD}(y_{datamax} - y_{datamin}) + y_{datamin}$$

The scaled OALHD was used to develop javelin throw computer experiments using the simulators for the horizontal and vertical displacements, horizontal and vertical velocities as well as the resultant velocity as shown in Equation 2 through Equation 6 to produce outputs which constitute the computer experimental results.

$$y_1 = x_3.cos(x_2).x_1 \qquad (2)$$
$$y_2 = x_3^2.\sin^2(x_2)/2g \qquad (3)$$
$$y_3 = x_3.cos(x_2) \qquad (4)$$
$$y_4 = x_3.\sin - gx_1 \qquad (5)$$
$$y_5 = SQRT\left(y_3^2 + y_4^2\right) \qquad (6)$$

From equations (1) to (6), y_1 and y_2 are the horizontal and vertical displacements, y_3 and y_4 are the horizontal and vertical velocities, y_5 is the resultant velocity and g is the acceleration (in ms^{-2}) due to gravity and is given as 9.81 m/s^2.

III. Analysis

The analysis in this study comprised the development of computer experiments.This development was done using Equation 1 and the experimental result was given in Table 3 and Table 4. The time of flight, angle and the lauched velocity were analysed using the assumed ranges of values and the results were appropriately given in this study.

IV. Results

The results of this study are presented in Tables 3-5. The OA(25,3)LHD adopted as constructed is presented in Table 1 along with the assumed ranges of values for javelin throw variables in Table 2. The projection properties of the design adopted in the development of javelin throw computer experiment is given in Fig. 1 and the picture of a javelin thrower is provided in Fig. 2 to have an overview of the process in practice. The projection plots for the javelin throw experiment with and without OALHD are given in Fig. 3 and Fig. 4, respectively.

TABLE 1: **OA (25, 3)LHD CONSTRUCTED FOR COMPUTER EXPERIMENT**

Orthogonal Array (D)				**Design Points (L)**		
	x_1	x_2	x_3	x_1	x_2	x_3
1	0	0	0	0.0200	0.0200	0.0200
2	0	1	1	0.0600	0.2200	0.2200
3	0	2	2	0.1000	0.4200	0.4200
4	0	3	3	0.1400	0.6200	0.6200
5	0	4	4	0.1800	0.8200	0.8200
6	1	0	1	0.2200	0.0600	0.2600
7	1	1	2	0.2600	0.2600	0.4600
8	1	2	3	0.3000	0.4600	0.6600
9	1	3	4	0.3400	0.6600	0.8600
10	1	4	0	0.3800	0.8600	0.0600
11	2	0	2	0.4200	0.1000	0.5000
12	2	1	3	0.4600	0.3000	0.7000
13	2	2	4	0.5000	0.5000	0.9000
14	2	3	0	0.5400	0.7000	0.1000
15	2	4	1	0.5800	0.9000	0.3000
16	3	0	3	0.6200	0.1400	0.7400
17	3	1	4	0.6600	0.3400	0.9400
18	3	2	0	0.7000	0.5400	0.1400
19	3	3	1	0.7400	0.7400	0.3400
20	3	4	2	0.7800	0.9400	0.5400
21	4	0	4	0.8200	0.1800	0.9800
22	4	1	0	0.8600	0.3800	0.1800
23	4	2	1	0.9000	0.5800	0.3800
24	4	3	2	0.9400	0.7800	0.5800
25	4	4	3	0.9800	0.9800	0.7800

where X_i (i = 1, 2, 3) denote the ith input variables

TABLE 2: INPUT VARIABLES FOR JAVELIN THROW SIMULATOR

Variable	Variable name	Minimum	Maximum
X_1	Time of Flight (s)	20	60
X_2	Angle (degree)	15	45
X_3	Launched Velocity (m/s)	5	15

TABLE 3: EXPERIMENTAL DATA FOR JAVELIN THROW COMPUTER EXPERIMENTS (WIITH OALHD)

X1	X2	X3	Y1	Y2	Y3	Y4	Y5
20.800	15.600	5.200	104.176	2.073	5.008	-202.650	41066.868
22.400	21.600	7.200	149.954	8.021	6.694	-217.094	47129.590
24.000	27.600	9.200	195.674	22.223	8.153	-231.178	53443.119
25.600	33.600	11.200	238.815	50.124	9.329	-244.938	59994.632
27.200	39.600	13.200	276.645	98.146	10.171	-258.418	66779.865
28.800	16.800	7.600	209.538	7.083	7.276	-280.331	78585.671
30.400	22.800	9.600	269.037	21.443	8.850	-294.504	86732.518
32.000	28.800	11.600	325.285	50.935	10.165	-308.332	95068.411
33.600	34.800	13.600	375.232	103.170	11.168	-321.854	103590.188
35.200	40.800	5.600	149.219	24.022	4.239	-341.653	116726.666
36.800	18.000	10.000	349.989	17.911	9.511	-357.918	128105.173
38.400	24.000	12.000	420.962	46.625	10.963	-371.823	138252.463
40.000	30.000	14.000	484.974	99.898	12.124	-385.400	148533.160
41.600	36.000	6.000	201.931	26.371	4.854	-404.569	163676.309
43.200	42.000	8.000	256.831	63.094	5.945	-418.439	175091.159
44.800	19.200	12.400	524.620	37.972	11.710	-435.410	189581.915
46.400	25.200	14.400	604.569	88.902	13.030	-449.053	201648.398
48.000	31.200	6.400	262.768	26.891	5.474	-467.565	218616.681
49.600	37.200	8.400	331.866	65.204	6.691	-481.497	231839.715
51.200	43.200	10.400	388.161	132.265	7.581	-495.153	245176.206
52.800	20.400	14.800	732.430	71.622	13.872	-512.809	262973.208
54.400	26.400	6.800	331.342	25.347	6.091	-530.640	281579.320
56.000	32.400	8.800	416.085	63.460	7.430	-544.645	296637.876
57.600	38.400	10.800	487.520	132.118	8.464	-558.348	311752.047
59.200	44.400	12.800	541.399	242.003	9.145	-571.796	326951.019

TABLE 4: EXPERIMENTAL DATA FOR JAVELIN THROW COMPUTER EXPERIMENT (WITHOUT OALHD)

X1	X2	X3	Y1	Y2	Y3	Y4	Y5
20.000	15.000	5.000	96.593	1.707	4.830	-194.906	37988.312
21.667	16.250	5.417	112.673	2.537	5.200	-211.034	44535.459
23.333	17.500	5.833	129.811	3.659	5.563	-227.146	51595.252
25.000	18.750	6.250	147.958	5.143	5.918	-243.241	59166.186
26.667	20.000	6.667	167.056	7.066	6.265	-259.320	67246.793
28.333	21.250	7.083	187.049	9.518	6.602	-275.383	75835.649
30.000	22.500	7.500	207.873	12.596	6.929	-291.430	84931.372
31.667	23.750	7.917	229.464	16.408	7.246	-307.462	94532.629
33.333	25.000	8.333	251.752	21.072	7.553	-323.478	104638.134
35.000	26.250	8.750	274.667	26.718	7.848	-339.480	115246.653
36.667	27.500	9.167	298.134	33.482	8.131	-355.467	126357.005
38.333	28.750	9.583	322.075	41.513	8.402	-371.441	137968.063
40.000	30.000	10.000	346.410	50.968	8.660	-387.400	150078.760
41.667	31.250	10.417	371.055	62.016	8.905	-403.346	162688.086
43.333	32.500	10.833	395.925	74.831	9.137	-419.279	175795.093
45.000	33.750	11.250	420.931	89.598	9.354	-435.200	189398.897
46.667	35.000	11.667	445.983	106.508	9.557	-451.108	203498.676
48.333	36.250	12.083	470.986	125.763	9.745	-467.005	218093.678
50.000	37.500	12.500	495.846	147.566	9.917	-482.890	233183.218
51.667	38.750	12.917	520.465	172.129	10.074	-498.765	248766.680
53.333	40.000	13.333	544.743	199.670	10.214	-514.629	264843.521
55.000	41.250	13.750	568.579	230.407	10.338	-530.484	281413.269
56.667	42.500	14.167	591.870	264.564	10.445	-546.329	298475.528
58.333	43.750	14.583	614.511	302.365	10.534	-562.165	316029.976
60.000	45.000	15.000	636.396	344.037	10.607	-577.993	334076.369

TABLE 5: VARIANCE ESTIMATES OF THE INPUT VARIABLES FOR JAVELIN THROW EXPERIMENT

Variable	**Variable name**	**Variance (OALHD)**	**Variance (Without OALHD)**
X_1	Time of Flight (s)	11.7757	12.2663
X_2	Angle (degree)	8.8318	9.1998
X_3	Launched Velocity (m/s)	2.9439	3.0666

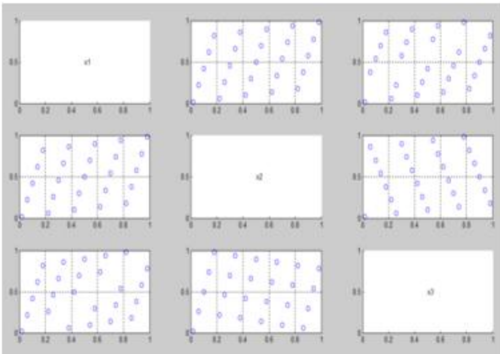

Figure 1: Projection properties of OA (25, 3) LHD

Figure 1 showed the projection property of the OA (25, 3) LHD given in Table 1.

Figure 2: A javelin thrower in action

Fig. 2 showed how a javelin is thrown. This picture was extracted from www.tutorialspoint.com.

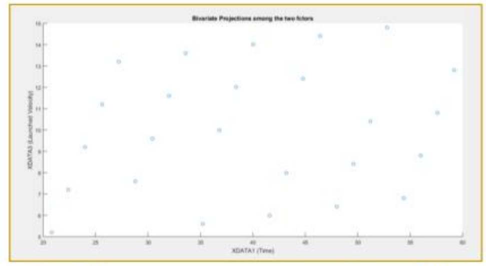

Figure 3: Projection of launched velocity against the time of flight

Figure 3 showed the projection of the experimental data with OALHD based on the data presented in Table 3.

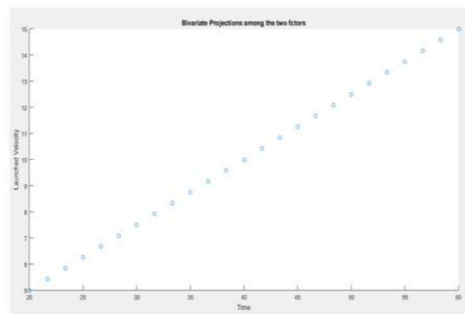

Figure 4: Projection of launched velocity against the time of flight

Figure 4 showed the projection of the experimental data without OALHD based on the data presented in Table 4.

V. DISCUSSIONS

The OA (25, 3) LHD adopted for developing javelin throw computer experiments contained 25 experimental runs with three factors as mentioned earlier. Each design point appeared once and only once for each input variable in the javelin computer experiment. This means that the scheme is advantageous as the stratification is maintained in all the three input variables involved in the experiment. This can be confirmed in Table 1 and it also gives credence to the result provided in Table 3 for javelin throw computer experiment with OALHD. The result provided in Table 4 was poor as each sample was close to one another and cannot be used to properly mimic the real life javelin throw experiment. The estimates of the variance were also higher as shown in Table 5. Based on the output of the javelin throw computer experiment, the distance achieved for the javelin throw peaked at the launched angle of 20.4°.

VI. Conclusion

This study develops a javelin throw as a computer experiment using orthogonal array Latin hypercube design (OALHD). A javelin thrower will be helped to achieve better performance(s) through this study as it serves as a prototype before embarking on a javelin throw competition. The focus of this study is to model and analyse a javelin throw computer experiment for a future research. This study concludes that OALHD can be adopted whenever interest is focused on performing either a conventional or computer experiment on real life situations.

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