

# Numerical Simulation of Spear Motion as Game Items

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**Abstract.** Game development in 3D is mostly done by characters, items and the environment. Game items such as character weapons modeled in 3D will be the attraction of a game. In this paper, spear motion as a game items is modeled in 3D. Nonlinear Equations Six Degrees of Freedom (6 DOF) are used for mathematical models of spear motion. The parameters studied in the motion model are: geometry, mass and aerodynamics. Spear aerodynamic parameters were analyzed using the Datcom method. Numerical simulation of mathematical models of spear motion with variations in the initial velocity of the throw and the direction of the throw. From the results of numerical simulation, the maximum range  $R = 131.7$  m at the initial velocity  $V_0 = 40$  m/s, the direction of throw (angle  $\theta_0 = 35$  deg, angle  $\varphi_0 = 10$  deg,  $\psi_0 = 0$  deg). And the maximum height  $H_{max} = 12.18$  m is achieved at the initial velocity  $V_0 = 20$  m/s, direction of throw (angle  $\theta_0 = 35$  deg, angle  $\varphi_0 = 40$  deg, angle  $\psi_0 = 0$  deg).

**Keywords:** spear motion, 6 DOF, aerodynamics, numerical simulation, 3D

## 1. Introduction

Since the 2000s the development of games has been very rapid [1]. Starting from a simple game, it turns into a complex 2D to 3D. 3D games are preferred over 2D games. Even in the world of education, 3D educational games have a better level of effectiveness than 2D [2]. 3D game development is mostly done. Reconstruction 2D image display becomes 3D to improve game quality [3,4].

One of the game elements according to Rouse [5] is game items. Game items can be purchased, collected, used and manipulated in various ways by the player in carrying out his mission. For example, the type of weapon, the type of fighter begins with property and behavior that is simple to complex. One weapon item in the Reog Ponorogo game scenario especially level 2 [6] is a spear. Not only modeling the shape of the spear in 3D, the model of spear motion in 3D space makes the game more interesting because of its movements like real.

Modeling spear motion or such as spear has been done. The movement of spears in the air has been formulated by examining the elasticity of the spear and its dynamic motion [7]. The spear motion model that is modeled is still in 2D space, namely the x axis and z axis. Maryniak et al. [8] modeled javelin thrown in 2D space. The javelin movement model in 2D is also done using the 3 DOF equation [9]. The spear motion model as a game item in this paper is modeled in 3D by examining the parameters of geometry, mass and aerodynamics.

The aerodynamic parameters of a test object are very important in the field of aerodynamic application science [9]. Moniuszko et al. [10] and Maryniak et al. [8] have modeled the dynamic motion of objects



when in the air and performed aerodynamic tests. Research on the calculation and analysis of aerodynamic characteristics on flat plates and endwall areas was carried out using CFD [12]. CFD software has high accuracy in the calculation and analysis of aerodynamic characteristics, but takes a long time in the calculation process. The Datcom method is used to calculate and analyze the RX 250 LAPAN aerodynamic characteristics [12]. The accuracy of the Datcom method using Digital Datcom Software is lower than that of CFD but the time needed in the calculation process is faster and easier with accurate results. The spear aerodynamic characteristics in this paper were calculated using the Datcom method.

The spear motion model designed is numerically simulated as an analysis of mathematical spear motion. The simulation is carried out with variations in the spear throwing angle and the initial speed of the spear thrown so that the maximum range  $R$  and the maximum height of the spear  $H$  can be known. The spear motion model is then implemented in a 3D model in a game using the Unity game engine.

## 2. Reference frame and kinematics of spear motion

The coordinate system of spear  $Ox_b y_b z_b$  of the earth reference frame  $Ox_h y_h z_h$  is illustrated in figure 1. Relationship of kinematics between linear elements velocity  $V_x, V_y, V_z$  in the earth's reference frame system with linear elements velocity  $u, v, w$  in the spear coordinate system described in equation (1). Please follow these instructions as carefully as possible so all articles within a conference have the same style to the title page. This paragraph follows a section title so it should not be indented.

$$\begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix} = \begin{bmatrix} \dot{X} \\ \dot{Y} \\ \dot{Z} \end{bmatrix} = \begin{bmatrix} \cos \psi \cos \theta & \cos \psi \sin \theta \sin \phi - \cos \phi \cos \psi & \cos \psi \sin \theta \sin \phi + \sin \phi \cos \psi \\ \sin \psi \sin \theta & \sin \psi \sin \theta \sin \phi - \sin \phi \cos \psi & \sin \psi \sin \theta \cos \phi - \sin \phi \cos \psi \\ -\sin \theta & \sin \phi \cos \theta & \cos \phi \cos \theta \end{bmatrix} \begin{bmatrix} u \\ v \\ w \end{bmatrix}$$

$$\begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix} = \begin{bmatrix} \dot{X} \\ \dot{Y} \\ \dot{Z} \end{bmatrix} = C_b^h \begin{bmatrix} u \\ v \\ w \end{bmatrix} \quad (1)$$

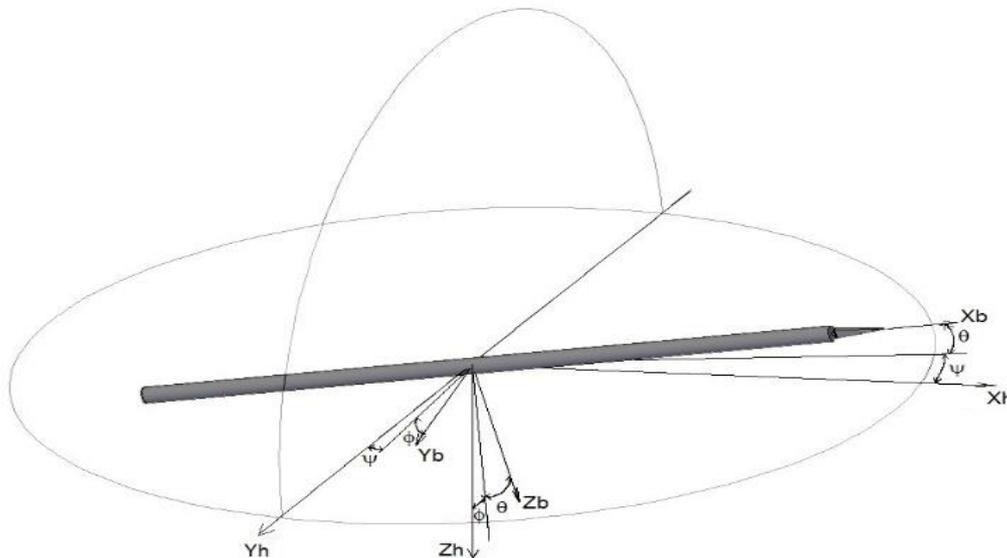


Figure 1. Spear coordinate system for the reference frame (earth coordinate system)

### 2.1. Wind Coordinate System

The axis of the wind coordinate system determines the direction of the lance's flight path while in the air. The wind coordinate system is shown in Figure 2. The positive  $x_w$  axis is the same as the spear speed vector. The spear translation speed in the wind coordinate system is transformed into the spear coordinate system according to equation (2).

$$\begin{cases} u \\ v \\ w \end{cases} = \begin{cases} V \cos \alpha \cos \beta \\ V \sin \beta \\ V \sin \alpha \cos \beta \end{cases} \quad (2)$$

$$\bullet V = \sqrt{u^2 + v^2 + w^2} \quad (3)$$

$$\bullet \text{Attack angle } \alpha = \arctan\left(\frac{w}{u}\right) \quad (4)$$

$$\bullet \text{Sideslip angle } \beta = \arcsin\left(\frac{v}{V}\right) \quad (5)$$

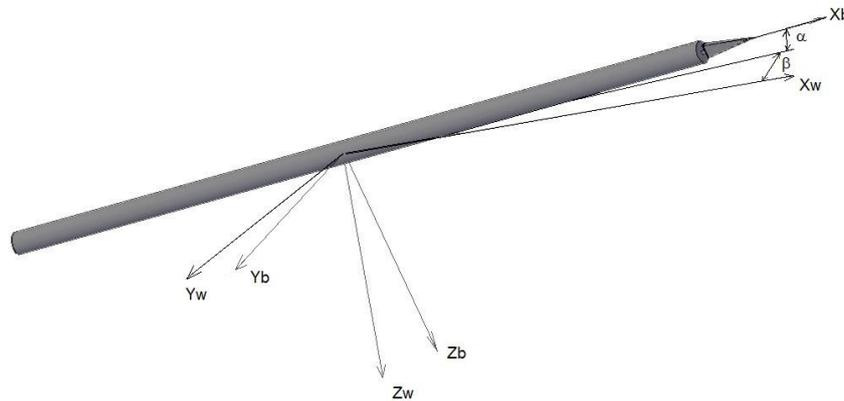


Figure 2. Relationship of wind coordinate system and spear coordinate system

### 3. Equation of Spear motion

This mathematical equation of spear motion is the equation of the six degrees of freedom (6 DOF). This equation is based on Newton's Second Law and was derived by Euler. Equation The Newton equation follow equation (6) and (7).

$$\sum \Delta F = \frac{d(mV)}{dt} = m \left( \frac{dV_b}{dt} + \omega_b \times V_b \right) + \dot{m}V_b \quad (6)$$

$$\sum \Delta M = I\dot{\omega}_b + \omega_b \times (I\omega_b) + \dot{I}\omega_b \quad (7)$$

$\sum \Delta F = [F_x \ F_y \ F_z]^T$  is the total force vector on the spear coordinate system,  $V_b = [u \ v \ w]^T$  is vector of velocity on the spear coordinate system and  $\omega_b = [p \ q \ r]^T$  is vector of angular velocity from a spear.  $\sum \Delta M = [M_x \ M_y \ M_z]^T$  is vector of the total force moment in the spear coordinate system and  $I$  is the inertial tensor. The spear mass is fixed, so that  $\dot{m} = 0$ . Equation (6) is described as equation (8) and equation (7) is described as equation (9). Equation (8) is the equation of translational motion and equation (9) is an equation of rotational motion.

$$\dot{u} = \frac{F_{ax} + F_{gx}}{m} - qw + rv$$

$$\dot{v} = \frac{F_{ay} + F_{gy}}{m} - pw + ru$$

$$\dot{w} = \frac{F_{az} + F_{gz}}{m} - pv + qu$$

$$\begin{aligned} \dot{p} &= \frac{M_x I_{zz}}{\Delta} - \frac{[I_{zz}(I_{zz} - I_{yy})]qr}{\Delta} \\ \dot{q} &= \frac{M_{yy}}{I_{yy}} - \frac{(I_{zz} - I_{xx})pr}{I_{yy}} \\ \dot{r} &= \frac{M_z I_{xx}}{\Delta} - \frac{[I_{xx}(I_{xx} - I_{yy})]}{\Delta} \end{aligned} \quad (8)$$

Gravitational force on the spear coordinate system:

$$\begin{bmatrix} F_{gx} \\ F_{gy} \\ F_{gz} \end{bmatrix} = C_b \begin{bmatrix} 0 \\ 0 \\ mg \end{bmatrix} \quad (10)$$

Aerodynamics forces:

$$\begin{aligned} F_{ax} &= \frac{1}{2} \rho l d V^2 (C_x + C_{xq} q) \\ F_{ay} &= \frac{1}{2} \rho l d V^2 (C_y + C_{yb} \beta) \\ F_{az} &= \frac{1}{2} \rho l d V^2 (C_z + C_{zq} q) \end{aligned} \quad (11)$$

And aerodynamics moment is follow equation [14]

$$\begin{aligned} M_x &= \frac{1}{2} \rho S V^2 l C_l \\ M_y &= \frac{1}{2} \rho S V^2 c (C_m + C_{mq} q) \\ M_z &= \frac{1}{2} \rho S V^2 l C_n \end{aligned} \quad (12)$$

$\rho$  : air density

$l$  : length of the spear

$d$  : maximum spear diameter

$V$  : spear velocity

$c$  : spear diameter

$\Delta = I_{xx} \cdot I_{yy} \cdot I_{zz}$

$I_{xx}, I_{yy}, I_{zz}$  : inertial tensor

$C_x, C_y, C_z$  : aerodynamic coefficient on the spear coordinate system

$C_{xq}, C_{yb}, C_{zq}$  : aerodynamic coefficients obtained from the calculation of the datcom method

$C_l, C_m, C_n$  : rolling moment, pitching momen and yawing moment

#### 4. Calculation of Spear Aerodynamic Parameters

The calculation of the spear aerodynamic parameter is obtained from Digital Datcom results by entering the geometry of spear. In addition to calculating aerodynamic parameters. spear mass geometry is needed to determine the center of mass and the moment of spear inertia. The location of the spear mass center is determined by the equation (13)

$$x_c = \frac{\sum_{i=1}^3 m_i x_i}{\sum_{i=1}^3 m_i}; \quad y_c = \frac{\sum_{i=1}^3 m_i y_i}{\sum_{i=1}^3 m_i}; \quad z_c = \frac{\sum_{i=1}^3 m_i z_i}{\sum_{i=1}^3 m_i}$$

(13)

The inertia moment of spear :

$$\begin{aligned}
 I_{xx} &= \sum_{i=1}^3 m_i (y_i^2 + z_i^2) & J_{xy} &= J_{yx} = \sum_{i=1}^3 m_i x_i y_i \\
 I_{yy} &= \sum_{i=1}^3 m_i (x_i^2 + z_i^2) & J_{xz} &= J_{zx} = \sum_{i=1}^3 m_i x_i z_i \\
 I_{zz} &= \sum_{i=1}^3 m_i (x_i^2 + y_i^2) & J_{zy} &= J_{yz} = \sum_{i=1}^3 m_i z_i y_i
 \end{aligned}$$

(14)

Spear material is iron, and spear wood material is areca nut. The shape of the spear follows the size of the spear in Table.1

Table 1. Spear Geometry<sup>1</sup>

Spear geometry	
Spear total length	330 cm
Head spear length	21 cm
length of the transition section	7 cm
the length of the wooden spear	302 cm
diameter of wood spear	4 cm
thick head spear	23 mm
maximum spear width	5 cm
total spear mass	4,55 kg
head spear mass	644 g
mass of the spear transition section	170 g
spear mass center (measured from head spear )	149.87 cm

From the Datcom calculation the coefficient value is obtained  $C_{xq}, C_{yb}, C_{zq}, C_l, C_m, C_n, C_D, C_L$  used in the equation (11) and (12).  $C_D, C_L$  used to determine the value of the aerodynamic coefficient on the spear coordinate system with the equation (15).

$$\begin{pmatrix} C_x \\ C_y \\ C_z \end{pmatrix} = \begin{pmatrix} C_L \sin \alpha - C_D \cos \alpha \cos \beta \\ -C_D \sin \beta \\ -C_D \sin \alpha \cos \beta - C_L \cos \alpha \end{pmatrix}$$

(15)

### 5. Numerical Simulation of Spear Motion

The numerical solution of equations (8) and (9) with Euler integration are described equations (16) and (17).

$$\begin{aligned}
 u(t) &= u_0 + \int_{t_0}^t \dot{u} dt \\
 v(t) &= v_0 + \int_{t_0}^t \dot{v} dt \\
 w(t) &= w_0 + \int_{t_0}^t \dot{w} dt
 \end{aligned}$$

(16)

<sup>1</sup> The Results of interviews with Batoro Katong Heritage Guard

$$\begin{aligned}
 p(t) &= p_0 + \int_{t_0}^t \dot{p} dt \\
 q(t) &= q_0 + \int_{t_0}^t \dot{q} dt \\
 r(t) &= r_0 + \int_{t_0}^t \dot{r} dt
 \end{aligned}
 \tag{17}$$

Initial value  $p_0, q_0, r_0$  at  $t = 0$  is zero, also the initial value  $\alpha$  and  $\beta$  is zero. Initial value  $u_0, v_0, w_0$  at  $t = 0$  according to the eq. (2)

$$\begin{Bmatrix} u_0 \\ v_0 \\ w_0 \end{Bmatrix} = \begin{Bmatrix} V_0 \cos \alpha \cos \beta \\ V_0 \sin \beta \\ V_0 \sin \alpha \cos \beta \end{Bmatrix}
 \tag{18}$$

$V_0$  is initial throw speed. From the results of numerical solutions, equations (16) and (17), the value of  $V_x, V_y, V_z$  is obtained. Numerical solutions of eq. (1) is:

$$\begin{aligned}
 X(t) &= X_0 + \int_{t_0}^t V_x dt \\
 Y(t) &= Y_0 + \int_{t_0}^t V_y dt \\
 Z(t) &= Z_0 + \int_{t_0}^t V_z dt
 \end{aligned}
 \tag{19}$$

$X_0 = 0, Y_0 = 0, Z_0 = 1,8$ . Nilai  $Z_0 = 1,8$  is obtained from the average height of the person plus the length of the arm.

Figures 3,4,5 is a graph of the spear aerodynamic coefficient on the angle of attack at various Mach values. The value of  $C_D$  in figure 3 tends to decrease for the increase in Mach numbers. Minimum value of  $C_D$  at the angle of attack  $\alpha = 0$  deg. The  $C_L$  value shown in Figure 4 tends not to change for the increase in Mach numbers. This is because the range of Mach numbers taken is not too significant. Taking Mach number is based on the presence of spears. The value of  $C_m$  shown in figure 5 does not change for various Mach values. The value of  $C_m$  is negative in the range of  $-7 \text{ deg} < \alpha < 0 \text{ deg}$  and  $\alpha > 7 \text{ deg}$  indicating that the attack angle is the state of the spear in a static stable state according to longitudinal static stability.

Figures 6 and 7 are the results of several experimental examples. Figure 6 is one of the results of the study by throwing the direction of direction  $\varphi_0$  at the initial velocity  $V_0 = 20 \text{ m/s}$ ,  $\theta_0 = 35 \text{ deg}$ ,  $\psi_0 = 0$ . These results indicate that the greater angle  $\varphi_0$  causes the  $H_{max}$  value be higher. The value of  $\varphi_0$  also affects the range (flight distance) value  $R$ . Increasing value of  $\varphi_0$ , the value of  $R$  also increases. Exceptions at  $\varphi_0 > 30 \text{ deg}$ , the range gets smaller even though the  $H_{max}$  is greater. This shows that  $\varphi_0 = 30 \text{ deg}$  is  $\varphi_0$  optimum for flight distance  $R$  of spear. Figure 7 is a simulation result with variations in initial velocity  $V_0$  at  $\theta_0 = 35 \text{ deg}$ ,  $\varphi_0 = 10 \text{ deg}$ ,  $\psi_0 = 0 \text{ deg}$ . The results show that the initial velocity affects the magnitude of the  $R$ .

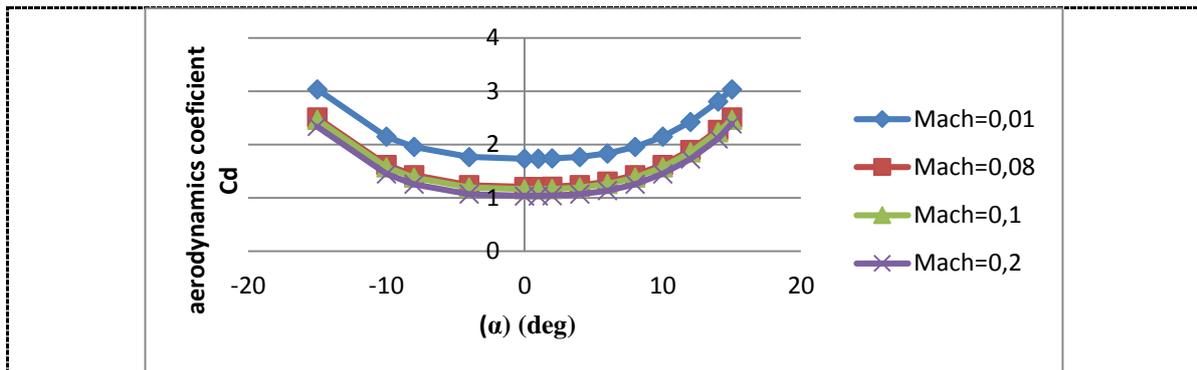


Figure 3.  $C_D$  graph of angle of attack for various Mach numbers

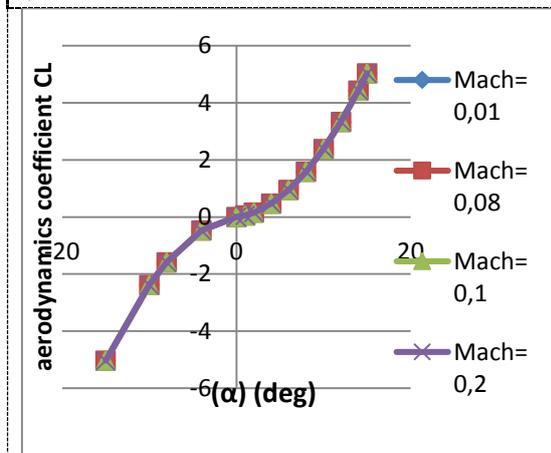


Figure 4.  $C_L$  graph of angle of attack for various Mach numbers

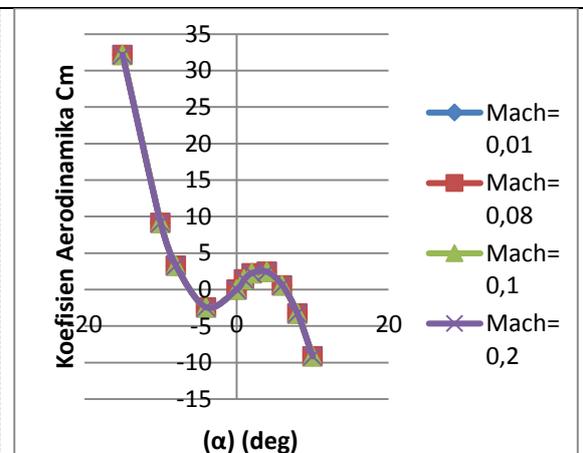


Figure 5.  $C_m$  graph of angle of attack for various Mach numbers.

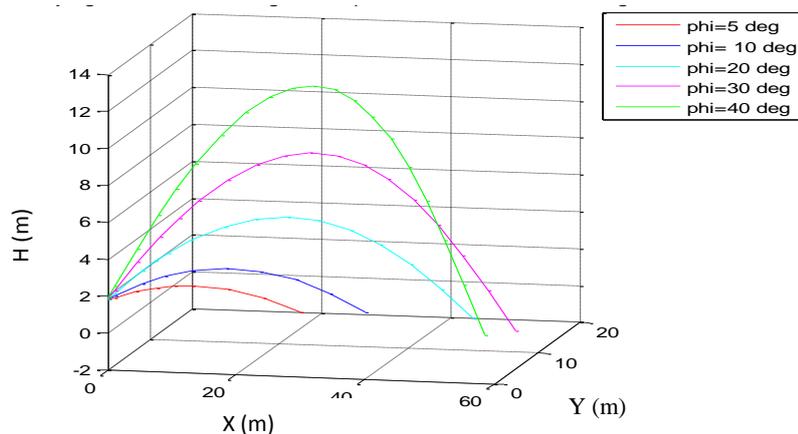


Figure 6. The simulation results of spear with variations in angle  $\phi_0$  at the initial velocity 20 m/s, the angle  $\theta_0$  35 deg, and the angle  $\psi_0 = 0$  deg

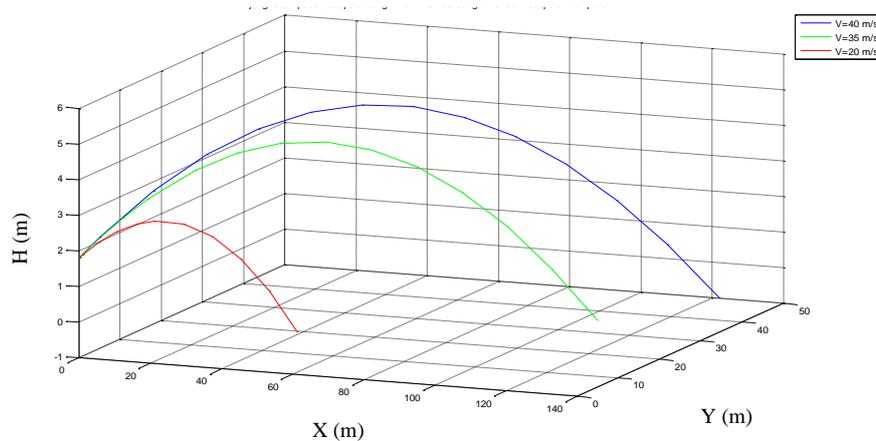


Figure 7. The simulation results of spear with variations in the initial velocity at the angle  $\theta_0 = 35$  deg, the angle  $\psi_0 = 0$  deg and the angle  $\varphi_0 = 10$  deg

## 6. Conclusion

The equation of spear motion using 6 DOF can be implemented in spear motion as a game item. The equation of motion used in 3D games with the amount of input entered is the spear mass, the inertia moment of spear, the initial velocity of the throw, the direction of the throw and the output is the position of spear X, Y, Z after being thrown.

The numerical simulation results of the equations of spear motion show the  $H_{max}$  of 12.18 m obtained at the initial velocity  $V_0 = 20$  m/s, the direction of throw  $\theta_0 = 35$  deg,  $\varphi_0 = 40$  deg,  $\psi_0 = 0$  deg and the maximum range  $R_{max}$  is 131.7 m at the initial velocity  $V_0 = 40$  m/s and the throw direction  $\theta_0 = 35$  deg,  $\varphi_0 = 10$  deg,  $\psi_0 = 0$  deg

## 7. References

- [1] Sibero C I 2010 Membuat Game 2D Menggunakan Game Maker. (Yogyakarta:Mediakom)
- [2] Eridani D 2013 *Thesis* Implikasi Game Edukasi 2D dan 3D: Mengenal Huruf dan Angka Terhadap Anak Usia 4 hingga 6 Tahun (Yogyakarta: Gajah Mada University)
- [3] Putra A R, Djunaidi 2013 Mempercantik Tampilan Game 2D Menjadi 3D De Kronik Van Diponegoro Menggunakan Teknik Mode 7 *J. Teknik Elektro* **5** 102
- [4] Adipranata R, Lim R, Setiawan A 2008 Rekonstruksi Obyek 3D dari Gambar 2D dengan Metode Generalized Voxel Coloring *J.Informatika* **9** 43-50
- [5] Agustin R D 2017 Kerangka Analisis Komponen Konsep dan Desain Game *J. Ilmiah Teknologi Informasi Terapan* **3(2)** 86-95
- [6] Muhima R R 2010 *P3SWOT Report* Surabaya
- [7] Muhima R R 2011 Pemodelan Gerak Tombak pada *Game* dengan Pertimbangan Aerodinamika *Proc.ITS 2011* Surabaya
- [8] Maryniak J, Ładyżyńska-Kozdraś E, Golińska E 2009 Mathematical Modeling and Numerical Simulations of Javelin Throw *J.Human Movement* Vol. **10(1)** 16-20
- [9] Hatton L 2007 Optimising The Javelin Throw in The Presence of Prevailing Winds *Faculty of Computing, Information Systems and Mathematics, University of Kingston*
- [10] Moniuszko J, Maryniak J, Ładyżyńska-Kozdraś E 2010 Modeling Dynamics and Aerodynamic Tests of a Sport Parachute Jumper during Flight in Sitfly Position *Acta of Bioengineering and Biomechanics*, Vol. **12** (3) 29-39
- [11] Nugroho G, Imaduddin F 2008 Penentuan Karakteristik Aerodinamika Aliran Melalui Airfoil Joukowski/ Pelat Datar pada Daerah *Endwall* *J. Teknologi dan kejuruan* Vol **31(1)** 39-49
- [12] Wibowo SS 2002 Perhitungan Karakteristik Aerodinamika dan Analisis Dinamika dan Kestabilan Gerak Dua Dimensi Pada Modus Longitudinal Roket RX 250 LAPAN Tugas Akhir (Bandung: Bandung Institut of Teknologi)

- [13] Wibowo S S 2010 *handout Digital Datcom* Bandung
- [14] Wibowo S S 2006 Virtual Reality Simulation of Wing in Surface Effect Craft, *Master Theses of Aeronautics and Astronautics* Bandung