# Design Details Document

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## I. Introduction

The theme of the competition revolves around playing rugby with robots. Both the robots can have the ability to kick the ball and there are numerous variations that can be applied to execute the tasks of the theme. The purpose of this report is to present Team KJSCE Robocon's solution with details about the mechanisms and sensor controls while justifying the same. *It is important to note that all the mechanisms designed, acknowledge the challenges posed by the chirality of the Arena.*

## II. Pass Robot

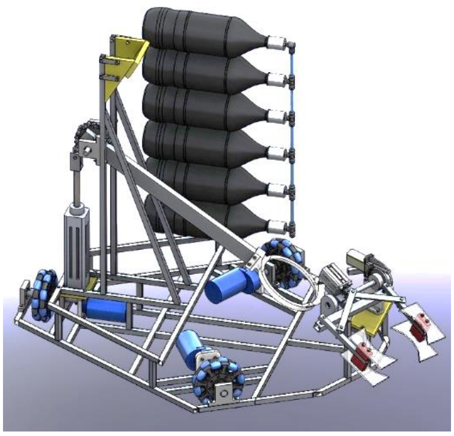


*Figure 1: Pass Robot*

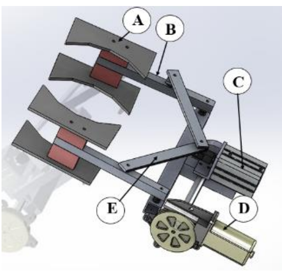
As per the applied strategy, the Pass robot (*see Figure 1*) is Semi-Autonomous and its primary goal is to complete Picking and Passing of the Try balls as quickly as possible. To achieve the same, the following ideas have been implemented.

### A. Movement

The Chassis is a 3 Wheel Holonomic Drive constructed using Aluminium Sections. The Ground clearance of the chassis is 20 mm. The motors for the Pass Robot are custom made, having 1000 RPM and a stall torque of 28 kg-cm.

The localization of the Pass Robot in the Passing Zone is done using 2 TF Mini LIDAR distance sensors mounted on the robot in the X-Y direction. An IMU is used as feedback for the angular movement of the robot, which is used to maintain stability during path traversal and to align the robot in a specific angular position.

### B. Picking Mechanism [2]




| | | |
|---|---|---|
| A | Acrylic Jaws |
| B | Gripping Link |
| C | Pneumatic Piston |
| D | Power Window Motor |
| E | Connecting Links |

*Figure. 2: Picking Mechanism*

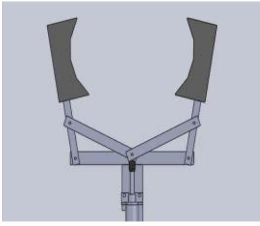


*Figure 3: Picking Piston actuated outwards (open)*

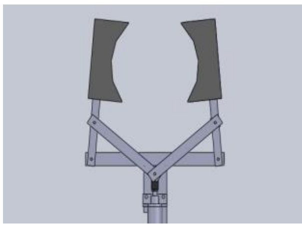


*Figure 4: Picking – Piston actuated inwards (gripped)*

An acrylic gripper actuated by a pneumatic piston is used to grip the ball from the ball rack. To transfer the ball into the throwing mechanism, the gripping mechanism is to be rotated about an axis that requires a torque of 15 kg-cm and hence a power window motor is used. A clevis joint at the end of the piston rod is attached to two linkages. These linkages are connected to hinged gripping arms and thus to gripping jaws (*see Figure 2*). The arms and plates are made using Aluminum.

Initially, when the stroke of piston is in the extended position, the arms are inclined outwards (*see Figure 3*). When the piston stroke closes, the arms rotate along the hinge and come closer (*see Figure 4*). The gripper comes in contact with the ball and hence grabs it. The gripper is arranged in such a way that it coincides with the Try ball's center. The gripping arms then grip the ball. In order to maintain the pressure inside the piston, an Electronic Pressure Regulator is connected to a 5/2 Solenoid which actuates the piston.

The gripped ball is rotated along a 15mm aluminium shaft using a power-window. Once rotation is complete, the piston stroke opens and the ball is placed in the throwing mechanism.

*Calculations:*

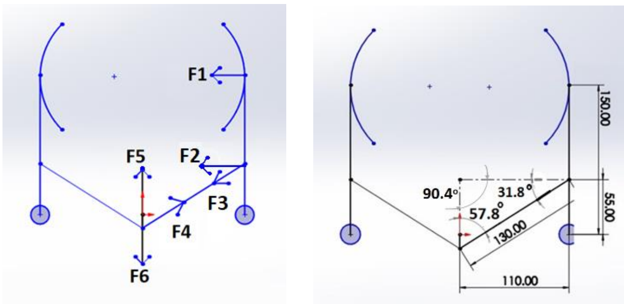



*Figure 5: Calculation Wireframe*

*Force required to hold Try ball:*

*F = Force required to hold Try ball.*

*$\mu$ = static coefficient of friction between acrylic and rubber = 0.8*

*m = mass of try ball = 0.35 kg*

$F = mg/\mu = 4.2875\ N$

*Force required in each arm* $(F_1) = F/2 = 2.14375\ N$

*Using class three lever equation:*

$F_1 * L_1 = F_2 * L_2$ ...$(L_1=150\ mm,\ L_2=55\ mm)$

$F_2 = 5.84659\ N$

*Resolving $F_2$ and $F_4$:*

$F_2 \cos(31.8) = F_3 = F_4 = 4.9689\ N$

$F_4 \cos(57.8) = F_5 = 2.6478\ N$

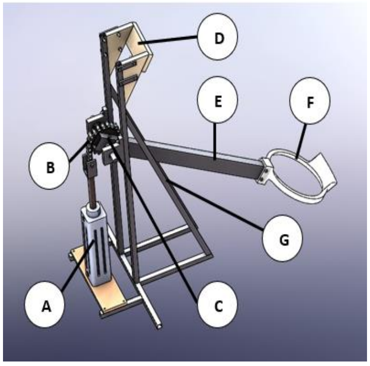
*Force required of piston stroke:*

$F_6 = 2 * F_5 = 5.2956\ N$

*The used* piston *(Mercury F25A-40) provides a constant force of 8N at 4 bars of pressure which is greater than $F_6$ and enough to pick the Try Ball.*

## C. Throwing Mechanism

### 1) Prototype 1




| | |
|---|---|
| A | Pneumatic Piston |
| B | Chain |
| C | Sprocket |
| D | Stopper |
| E | Throwing arm |
| F | Holder |
| G | Frame |

*Figure 6: Isometric View of Throwing Mechanism Prototype 1*

*Figure 7: Side View of Throwing Mechanism*

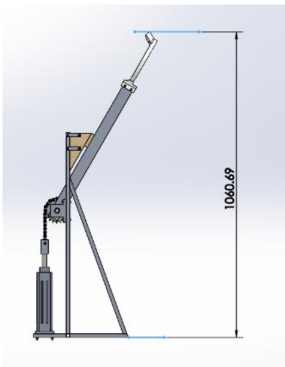


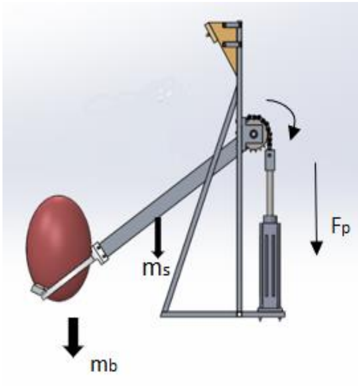

*Figure 8: Maximum Height of Throwing Mechanism*

The mechanism comprises of a pneumatic piston (Mercury AM-40) that launches the Try ball in a projectile motion towards the Try robot (*see Figure 6*). The linear motion of the piston is converted into rotary motion by using a chain and sprocket. One end of the chain is attached to the rod of the piston using an 'L' shaped plate. The chain goes over the sprocket and the other end of the chain is fixed to the face of the sprocket.

The throwing arm is attached to the shaft of the sprocket such that, when the piston is fully open, the throwing arm makes an angle of -40° with the horizontal (*see Figure 7*). On the other end of the throwing arm, a holder is attached for the Try ball. The picking mechanism places the Try ball in the holder. The use of the holder is to ensure that the initial inclination of the Try ball with respect to the throwing arm remains same for each throw.

Using a 5/2 Solenoid Valve to control the air flow and an Electronic Pressure Regulator, giving a finer control over throwing trajectory. When the piston retracts, the chain is pulled downwards which in-turn pulls the throwing arm upwards. The arm is brought to a stop using a stopper at 60° with the horizontal. During this process, the Try ball is released and thrown to the Receiving Zone.

### *Calculations:*




| | |
|---|---|
| S | Piston stroke length |
| $\theta_1$ | Initial angle |
| D | Sprocket pitch diameter |
| B | Bore diameter |
| P | Pressure in piston |
| $m_b$ | Weight of Try ball |
| $m_s$ | Weight of Throwing Arm |
| $v_p$ | Speed of piston |
| $\Omega$ | Rotational Velocity |
| $v_r$ | Speed of Try ball |
| $L$ | Length of Throwing arm |
| $\theta_2$ | Final Angle |

*Figure 9: Calculation Model*

$F_{net} = \frac{\pi b^2 p}{4}$ – *Internal friction of piston (21 N)*

*Torque due to piston* $= F_{net} * \frac{d}{2}$

*Torque due to gravity* $= L * m_b g \cos\theta + m_s g \frac{L}{2} \cos\theta$

*Net torque* $(\tau)$ = *Torque due to piston – Torque due to gravity*

$$= F_{net} * \frac{d}{2} - Lg \cos\theta (0.35 + \frac{m_s}{2})$$

*Practical Parameters:*

| | | |
|---|---|---|
| $s = 100\ mm$, | $\theta_1 = -40^o$, | $d = 80\ mm$, |
| $p = 4\ bar$, | $L = 0.6m$, | $m_b = 350g$, |
| $I = 0.1453\ kgm^2$ (from CAD file), | | $m_s = 265g$, |
| $b = 40\ mm$, | $\theta_2 = 60^o$ | |

*Speed Calculation:*

$$\tau\, d\theta = \frac{1}{2} m v^2 + \frac{1}{2} I \omega^2 \quad ...(1)$$

*Work done*

$$= \int_{-2\pi/9}^{\pi/3} \left(F_{net} * \frac{d}{2} - \text{Lg} \cos\theta \left(0.35 + \frac{m_s}{2}\right)\right) d\theta$$

$$= \frac{5\pi}{18} * d * F_{net} - 14.803 * L * (0.35 + \frac{m_s}{2})$$

$= 29.34\ J$

*From (1)*

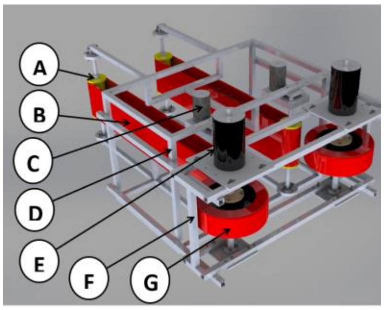
$$29.34 = \frac{1}{2} * 0.35 * v^2 + \frac{1}{2} * 0.1453 * \frac{v^2}{0.6^2}$$

$v = 8.82\ m/s$

*Using equations of projectile motions, the required velocity at release was 8m/s to achieve a distance of 6.2m. (Initial height of projectile was set to be 1.2 m)*

*The observed velocity (8.82 m/s) at 4 bars is enough to surpass the Kicking Zone and get to the Receiving Zone.*

2) *Prototype 2* [3]

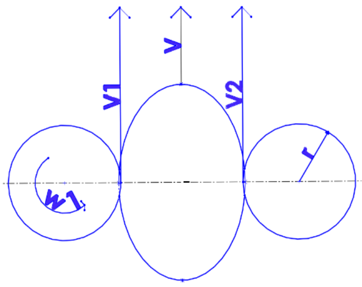



| | |
|---|---|
| A | Pulley |
| B | Belt |
| C | S. G. Mada Motor |
| D | Frame of Picking Mechanism |
| E | Amp-flow F24-150 Motor |
| F | Chassis of Throwing Mechanism |
| G | PU Wheels |

*Figure 10: Isometric View of Throwing Mechanism Prototype 2*

The mechanism is a combination of both the tasks, Picking and Throwing of the Try ball. The frame is constructed using Aluminium sections and the pulleys are made of Delrin (Industrial Plastic). The entire setup is placed in range of 30°- 45° from the horizontal (*see Figure 10*).

When this inclined mechanism is brought close to the ball rack, the rotating belt on the mechanism sucks the Try ball and starts moving it linearly along its axis with the help of bearings. The motors (S. G. Mada) actuated at low speed ensure the ball moves in the forward direction. The belt guides the Try ball between the rollers (which rotate at 1000 rpm using Amp-flow Motors) that throw the ball in its calculated trajectory.




| | |
|---|---|
| v | Velocity of rugby ball |
| $V_1$ | Tangential velocity of roller 1 |
| $V_2$ | Tangential velocity of roller 2 |
| $\omega_1$ | Angular velocity of roller |
| r | Radius of roller |

*Figure 11: Calculation Wireframe*

*(The calculations below are considering a No Slip case, Friction has not been considered)*

*The linear and angular speed of the ball depends on the circumferential speed of the rollers:*

$$V = r * \omega \qquad .....(1)$$

$$V = (V_1 + V_2) / 2$$

*ball shouldn't rotate about its own axis,*

$$V_1 = V_2$$

*Parameters:*

$r = 75$ mm

*Range of projectile motion:* $R = V^2 \sin 2\theta / g$

$\Theta$ = *angle of projectile* = $30^0$

*For R= 6m:*

$V = 8.244$ m/s

*Using (1),*

$\omega = V/r = 109.92$ rad/sec

$N = 1049.65$ rpm

*The required number of rotations per minute are 1050. This can be attained using the Amp-Flow F24-150-24V motors which are capable of providing speeds up to 4900rpm.*

## III. Try Robot

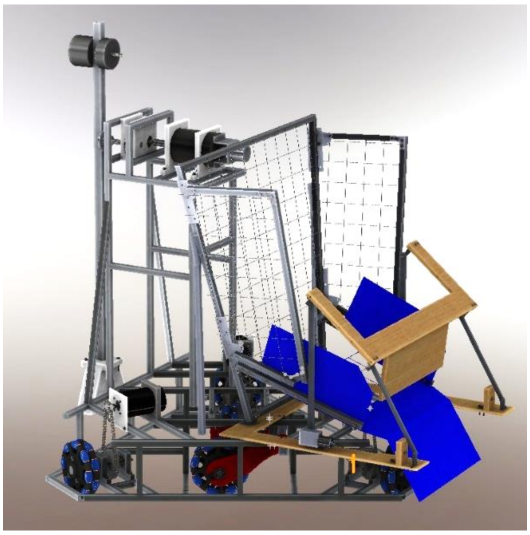
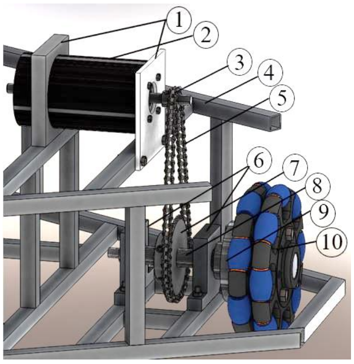


*Figure 12: Try Robot*

The Try Robot is a Semi-Autonomous 3-Wheel Holonomic Drive which is constructed using Aluminium Sections. Additionally, 2 passive Omni-wheels are mounted perpendicular to each other for Encoder readings in X-Y direction (*see Figure 12*).

### A. *Movement*




(1) Motor mounts
(2) Drive Motor
(3) Driving Sprocket
(4) Chassis
(5) Chain
(6) Bearing Holders
(7) Driven Sprocket
(8) Drive Shaft
(9) Drive Flange
(10)Omni Wheel

*Figure 13: Wheel Diagram with Identified Parts*

The ground clearance of the chassis is 20 mm. The driving motors, Amp-Flow F24-150-24V, are high RPM brushed DC motors. The stall torque is increased to 54 kg-cm from 18 kg-cm and operating torque to 36 kg-cm using Gear Reduction. The reduction ratio employed is 3:1. This configuration allows the drive to traverse at a peak velocity of 5 m/s with 36 kg-cm Torque.

Incremental encoders of 1024ppr map the X and Y coordinates of the traversal. The omni wheels connected to the encoder are suspended from the top layer of chassis with the help of tension springs to avoid slipping. Additionally, 2 Laser Distance sensors provide absolute X-Y coordinates of the Try robot with respect to the arena giving an extra parameter for accuracy.

An IMU is used for maintaining yaw stability. Its primary purpose is to align the robot at a particular angle, at the catching point and before kicking.

## B. *Catching Mechanism*

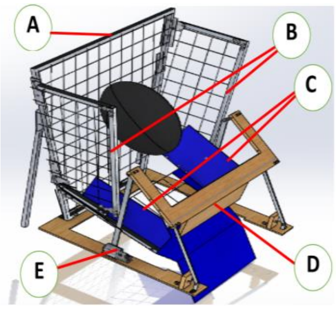



*Figure 14:Ball Arrival (Step 1)*

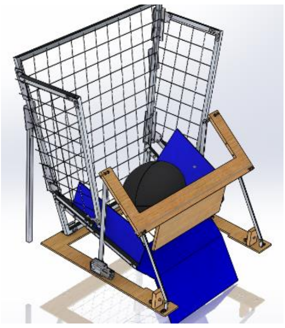


*Figure 15: Ball Resting Position (Step 2)*

*A - Net support* *B - Side Panel* *C - Side Support*
*D - Stopper* *E - Worm Geared Motor*

Thin Aluminium sections form a rhomboid frame and are used to hold the net in place. Panels are attached to the sides for additional contact area for the Try ball (*see Figure 14, 15*). To reduce the rebound at the joints and sections, memory foam is used along with nets.

Nylon net is used due to its light-weighted nature and its elasticity. The flexibility of the net dampens the impact of the ball as it approaches the Try robot.

## C. *Placing Mechanism*

### 1) *Prototype 1* [1]

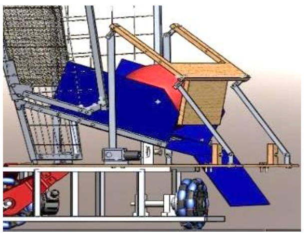


*Figure 16: Placing Step 1*

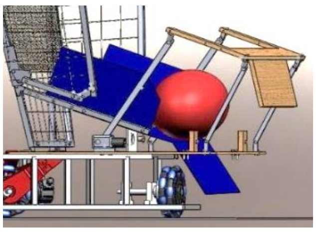


*Figure 17: Placing Step 2*

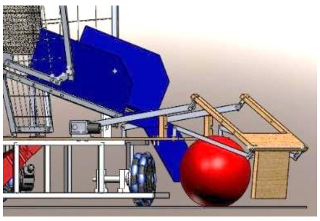


*Figure 18: Placing Step 3*

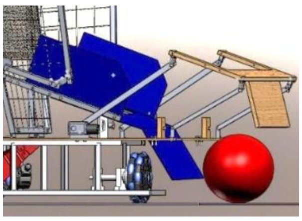
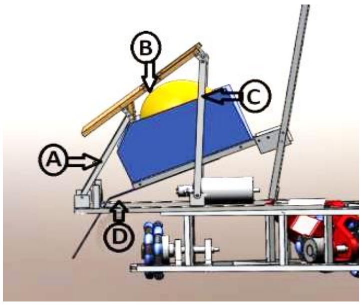


*Figure 19: Placing Step 4*

With the help of DC motor (Zerone DC 12V Geared Motor), the linkages are actuated (*see Figure 16*). When the linkages are in motion it allows the ball to slide through the slope and place the ball in the given region of the Try spot (*see Figure 17*).

The bottom slope (inclined at 55°) is designed such that, when the ball comes in contact with surface of the Try spot it remains in contact with the TR, hence satisfying rule 19 (A) (*see Figure 18*). The linkages are designed to ensure that the ball does not roll away too quickly or gets diverted once it touches the ground.

As the ball comes at halt between the bottom slope and stopper, the DC motor is actuated in reverse direction due to which the linkages retrace their path and while doing so the stopper retains its original position without touching the ball (*see Figure 19*). Hence the ball remains in the Try spot region satisfying rule 19(c).




| | | |
|---|---|---|
| A | Side Link | 207 mm |
| B | Shortest Link | 190 mm |
| C | Longest Link | 300 mm |
| D | Frame | 250 mm |

*Figure 20: Linkage Description Diagram*

As the TR reaches the Passing zone, ball is placed in the Try spot by following mechanism.

These lengths of linkages satisfy Grashof's rule for Class 2 Four Bar Mechanisms (double rocker mechanism):

***B+C > A+D***

### 2) *Prototype 2*

*Figure 21: Placing Step 1*


*Figure 22: Placing Step 2*

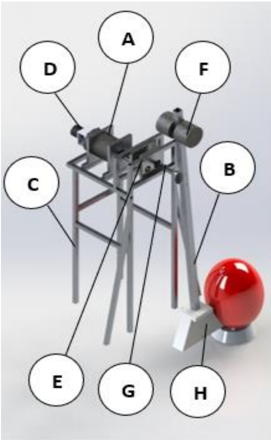
*A = Ramp* *B = Motor*

The Proposed mechanism contains an aluminium 'C' Shaped Frame of 12.7 x 12.7 mm sections, with the space covered by a taut net. The frame is coupled to a worm geared Zerone DC motor with a flange and supported by a bearing holder on the other side. A worm geared motor is used due to its non-back drivable nature.

The frame that holds the ball is actuated using the motor, this frame now turns into a ramp, this provides the ball a path to roll down and get placed in the placing region (*see Figure 21, 22*).

Here the net (nylon ropes of 1 mm thickness spaced at 10x10mm apart) provides a flexible contact. This allows the ball to slide off into the Try spot while still in contact with the robot.

### D. *Kicking Mechanism* [4][5]




| | |
|---|---|
| A | Amp-Flow E-30 150 |
| B | Kicking Section |
| C | Final Structure |
| D | Rotary Encoder |
| E | Dual Bearing Holder |
| F | Counterweight |
| G | Output Shaft |
| H | 3D printed ABS container for deadweight |

*Figure 23: Kicking Mechanism*

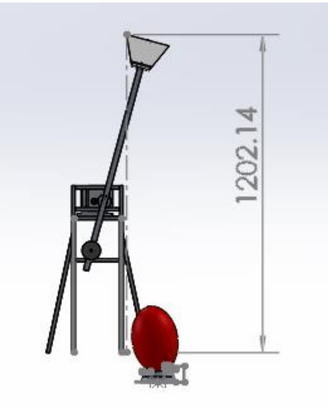



*Figure 24: Maximum Height of Mechanism*

*Figure 25: Point of Hitting Kick Ball*

The primary objective of the kicking mechanism is to kick the kick balls from Kicking zone 3 into the conversion post. A 20 x 20 mm aluminium section is used as the kicking leg and the surface which comes in contact with the ball is a 3D printed wedge at 26° angle which is made using ABS (Acrylonitrile butadiene styrene) material (*see Figure 23*).

The mechanism is driven by an [Amp-flow (E30-150) 24V]() brushed DC motor. This motor can provide the required angular acceleration of 13.33 rad/s$^2$. When the kicking movement starts, it is ensured that the mechanism attains the required velocity within the same rotation. The angled wedge at the bottom ensures that, only a single surface comes in contact with the kick ball following rule 20(b) (*see Figure 23*). The mechanism is made dynamically stable by positioning counter weights on the other side of the leg.

*Calculation*

$\omega_1$ = *angular velocity before striking the ball*
*m = mass of kick ball*
$\omega_2$ = *angular velocity after striking the ball*
*v = velocity imparted to the ball*
$\alpha$ = *angular acceleration of the kicking subassembly*
$T_1$ = *Torque provided by the motor*
$T_2$ = *Output torque of the kicking assembly*
*y = height of the ball at conversion post*
*r = distance from the output shaft where ball strikes*
*z = range of the projectile motion*
$\Theta$ = *total angular displacement*
$\Theta_1$ = *initial angle*

*Practical values:*

*Motor current rating = 32 A*

| | |
|---|---|
| $\omega_2 = 4.261$ rad/s, | $I = 0.36$ kgm$^2$ (from CAD) |
| $m = 0.35$ kg, | $T_1 = 1.2$ Nm |
| $\Theta = 11\pi/6$ rad, | $r = 0.6$ m |
| $\Theta_1 = 26°$, | $y = 1.8$ m |

$T_2 = 4\,T_1$ *…(Reduction ratio of 4:1)*
$T_2 = 4.8$ Nm

$T_2 = I * \alpha$
$\alpha = 13.333$ rad/s$^2$

$\omega_1^2 = 2 * \alpha * \Theta$
$\omega_1 = 12.393$ rad/s

*Since the collision is instantaneous, conserving angular momentum*
$I * \omega_1 = m * v * r + I * \omega_2$
$2.93 = 0.35 * v * 0.6$
$v = 13.94$ m/s

*From the general equation of projectile motion*

$$y = z * \tan(\Theta_1) - (g * z^2) / 2 * v^2 * \cos^2(\Theta_1)$$
$$1.8 = z * \tan(26) - (9.81 * z^2) / 2 * 13.94^2 * \cos^2(26)$$
$$z = \frac{-(-0.49) \pm \sqrt{0.49^2 - 4 * 0.031 * 1.8}}{2 * 0.031}$$

*z = 10 meter*

## IV. REFERENCES

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