Robotics II
Final Project
Due: 5/5/2021 by 2:30 pm

A differential drive mobile manipulator is shown below in the zeroed configuration. Following this, a the robot in a random configuration is depicted. The individual rigid bodies that comprise the robot as well as the mass parameters and the locations of the next body's body-fixed frame in the open kinematic frame are also depicted below. The .stl files are located on the course Canvas side under the "mm_2021" folder.

This robot is described by the following configuration coordinate vector:

$$\boldsymbol{\gamma}=\begin{bmatrix} x & y & \psi & \theta_{RW} & \theta_{LW} & \theta_1 & \theta_{R2} & \theta_{R3} & \theta_{R4} & \theta_{R5} & \theta_{R6} & \theta_{L2} & \theta_{L3} & \theta_{L4} & \theta_{L5} & \theta_{L6} \end{bmatrix}^T$$

and the following system speeds:

$$\boldsymbol{u}=\begin{bmatrix} \dot{\theta}_{RW} & \dot{\theta}_{LW} & \dot{\theta}_1 & \dot{\theta}_{R2} & \dot{\theta}_{R3} & \dot{\theta}_{R4} & \dot{\theta}_{R5} & \dot{\theta}_{R6} & \dot{\theta}_{L2} & \dot{\theta}_{L3} & \dot{\theta}_{L4} & \dot{\theta}_{L5} & \dot{\theta}_{L6} \end{bmatrix}^T .$$

The robot's kinematic differential equation is

$$\dot{\boldsymbol{\gamma}}=\boldsymbol{f}(\boldsymbol{\gamma},\boldsymbol{u})=\begin{bmatrix} \frac{r_R}{2}\cos(\psi)\dot{\theta}_{RW}+\frac{r_L}{2}\cos(\psi)\dot{\theta}_{LW} \\ \frac{r_R}{2}\sin(\psi)\dot{\theta}_{RW}+\frac{r_L}{2}\sin(\psi)\dot{\theta}_{LW} \\ \frac{r_R}{b}\dot{\theta}_{RW}-\frac{r_L}{b}\dot{\theta}_{LW} \\ \dot{\theta}_{RW} \\ \dot{\theta}_{LW} \\ \dot{\theta}_1 \\ \dot{\theta}_{R2} \\ \dot{\theta}_{R3} \\ \dot{\theta}_{R3} \\ \dot{\theta}_{R4} \\ \dot{\theta}_{R5} \\ \dot{\theta}_{R6} \\ \dot{\theta}_{L2} \\ \dot{\theta}_{L3} \\ \dot{\theta}_{L4} \\ \dot{\theta}_{L5} \\ \dot{\theta}_{L6} \end{bmatrix}$$

The generalized force input for the robot is:

$$\boldsymbol{F}_u=[\tau_{RW} \quad \tau_{LW} \quad \tau_1 \quad \tau_{R2} \quad \tau_{R3} \quad \tau_{R4} \quad \tau_{R5} \quad \tau_{R5} \quad \tau_{R6} \quad \tau_{L2} \quad \tau_{L3} \quad \tau_{L4} \quad \tau_{L5} \quad \tau_{L6}]^T$$

Assignment:

1) Create a MATLAB function called "mm_2021_draw" that draws the mobile manipulator in the configuration specified by γ.

2) Create a MATLAB function called "mm_2021" that accept two vectors: a vector comprised of the system's configuration coordinates and the system's speeds, and another vector comprised of the input torques. The function should return a single vector comprised of the rate of change of the configuration coordinates and system speeds. Assume that gravity is acting on the system and that this negligible friction in the joints.

3) Create a MATLAB function that implements a 4^{th} order Runge-Kutta integrator to solve the equations of motion from 2) and uses the results to animate the robot's motion. Also, on three figure windows, plot the configuration coordinates for the mobile robot vs. time on subplots in the first window, plot the configuration coordinates for the Link 1 and the right-hand part of the manipulator vs. time on subplots in the second window, and plot the the configuration coordinates for Link 1 and the left-hand part of the manipulator vs. time on subplots in the third window.

4) Design and implement a task-space control system that drives the tips of the left and right manipulators to a point specified with respect to the Chassis frame. The control system should also maintain the Chassis frame in an inertially fixed pose. Create an animation of the working system and save it as an .avi or .mp4. Generate a set of plots that show the manipulator is moving to the specified point.

Extra-Credit (10 points on Test 2)

Design and implement a control system for the mobile robot that drives the Chassis frame to a desired pose while holding the manipulators in a fixed configuration. Create an animation of the working system and save it as an .avi or .mp4. Generate a set of plots that show the manipulator is moving to the specified point.

Extra-Extra-Credit (5 more points on Test 2)

Design and implement a control system that drives the tips of both manipulators to a desired point anywhere in mobile manipulator's reachable workspace. Use motion of the mobile robot to accomplish this. Create an animation of the working system and save it as an .avi or .mp4. Generate a set of plots that show the manipulator is moving to the specified point.

Deliverables:

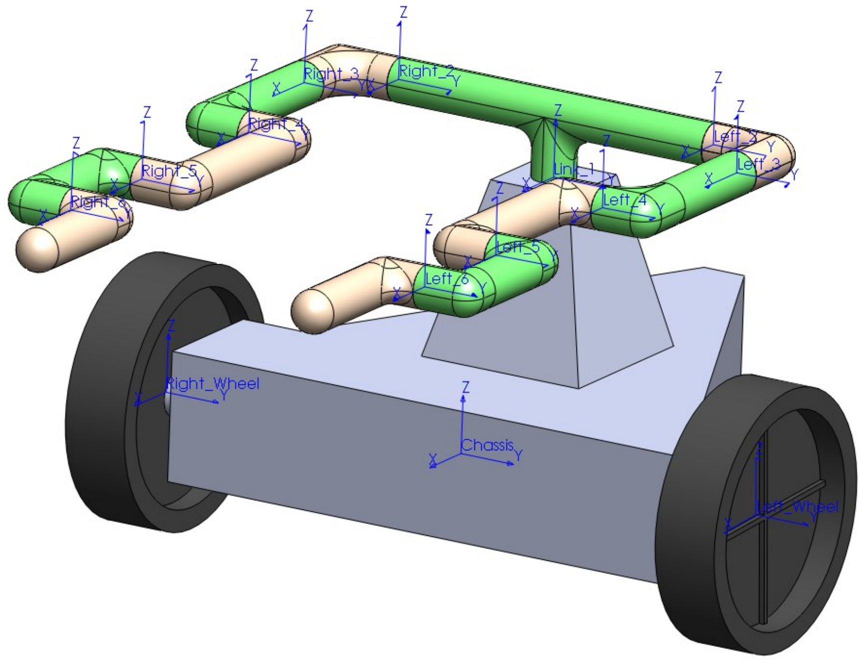
Compile a document that includes the following and upload it to Canvas.

1) Plots of the robot's motion in response to an arbitrary torque vector (show that step 3 is complete). State what this arbitrary torque vector is and describe why the motion you see makes sense. Upload the video file to Canvas and reference it in your description.

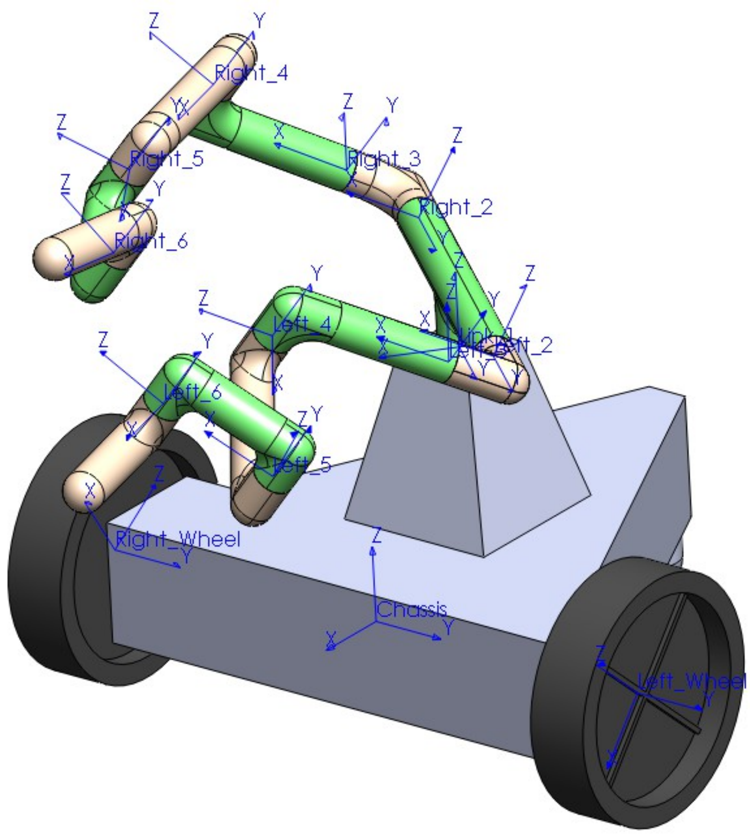
2) Plots of the robot's motion in driving the manipulator tips to a specified point (show that step 4 is complete). State what this point is and provide a discussion of robot's performance. Upload the video file to Canvas and reference it in you description.

Extra-Credit) Plots of the robot's motion in driving the Chassis frame to a desired pose. State what this pose is and provide a discussion of the robot's performance. Upload the video file to Canvas and reference it.

Extra-Extra-Credit) Plots of the robot's motion in driving the manipulators tips to a desired point anywhere in the reachable workspace. State what this point is and provide a discussion of the robot's performance. Upload the video file to Canvas and reference it in your discussion.

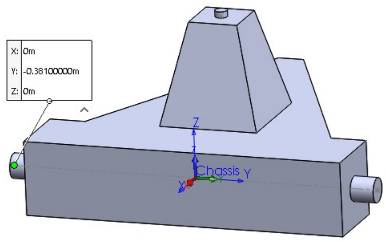


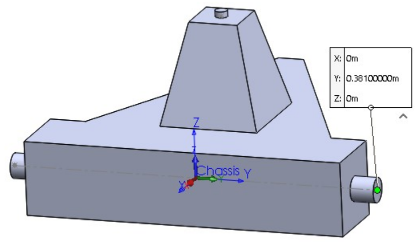
Zeroed Configuration

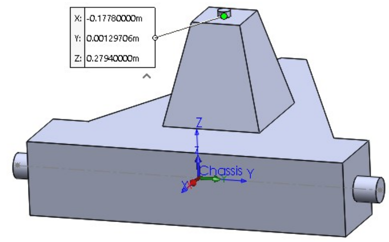


Random Configuration

Chassis:





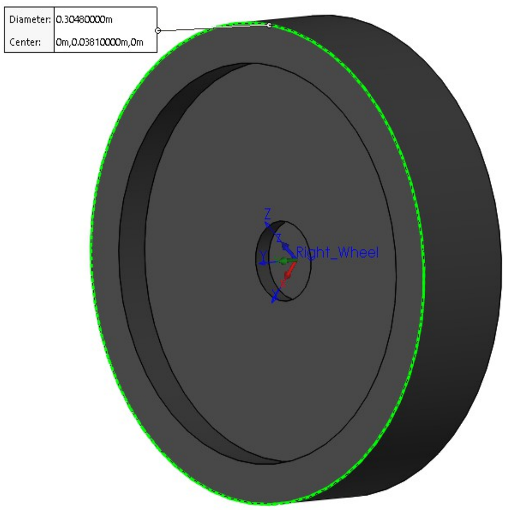


$$m_C = 5.73993897 \ (kg)$$

$${}^{C}_{C}\boldsymbol{r}_{cm} = \begin{bmatrix} -0.15125527 \\ 0.00114110 \\ 0.02044990 \end{bmatrix} (m)$$

$${}^{C}_{C}\boldsymbol{J} = \begin{bmatrix} 0.21072042 & 0.00112610 & 0.01755761 \\ 0.00112610 & 0.35520870 & -0.00015225 \\ 0.01755761 & -0.00015225 & 0.47082310 \end{bmatrix} (kg\, m^2)$$

Right Wheel:

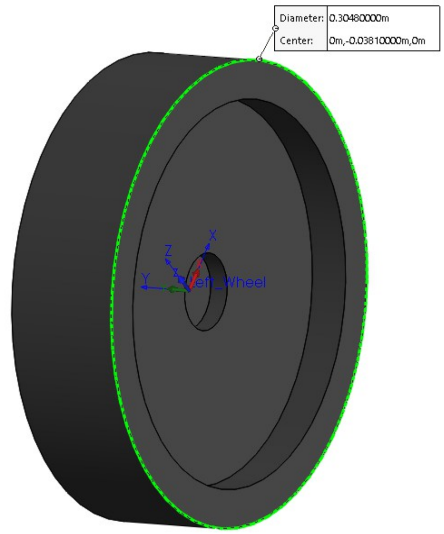


$$m_R = 3.43497773 \quad (kg)$$

$${}^R_R\boldsymbol{r}_{cm} = \begin{bmatrix} 0.00000000 \\ 0.00101881 \\ 0.00000000 \end{bmatrix} \quad (m)$$

$${}^R_R\boldsymbol{J} = \begin{bmatrix} 0.02780319 & 0.00000000 & 0.00000000 \\ 0.00000000 & 0.05338030 & 0.00000000 \\ 0.00000000 & 0.00000000 & 0.02780319 \end{bmatrix} \quad (kg\,m^2)$$

Left Wheel:

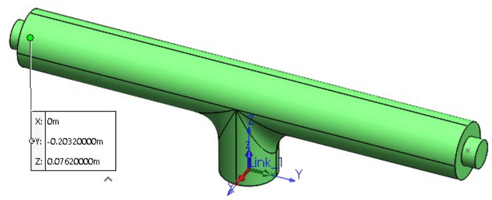


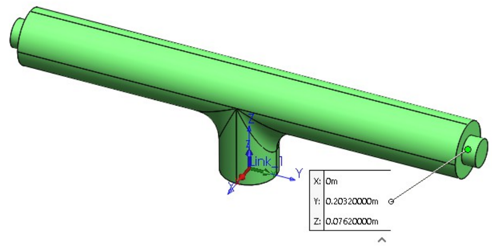
$$m_L = 3.43497773 \quad (kg)$$

$${}^L_L\boldsymbol{r}_{cm} = \begin{bmatrix} 0.00000000 \\ -0.00101881 \\ 0.00000000 \end{bmatrix} \quad (m)$$

$${}^L_L\boldsymbol{J} = \begin{bmatrix} 0.02780319 & 0.00000000 & 0.00000000 \\ 0.00000000 & 0.05338030 & 0.00000000 \\ 0.00000000 & 0.00000000 & 0.02780319 \end{bmatrix} \quad (kg\,m^2)$$

Link 1:



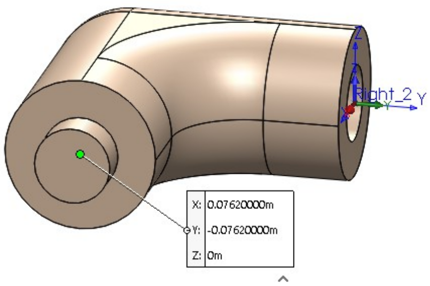


$$m_C = 0.96821600 \quad (kg)$$

$${}^{1}_{1}\boldsymbol{r}_{cm} = \begin{bmatrix} 0.00000000 \\ 0.00000000 \\ 0.07074779 \end{bmatrix} \quad (m)$$

$${}^{1}_{1}\boldsymbol{J} = \begin{bmatrix} 0.01739000 & 0.00000000 & 0.00000000 \\ 0.00000000 & 0.00538178 & 0.00000000 \\ 0.00000000 & 0.00000000 & 0.01232105 \end{bmatrix} \quad (kg\, m^2)$$

Right Link 2

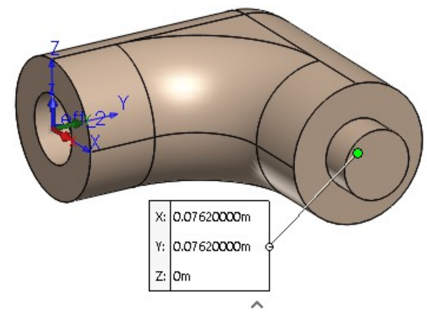


$$m_{R2} = 0.32122492 \quad (kg)$$

$$^{R2}_{R2}\boldsymbol{r}_{cm} = \begin{bmatrix} 0.01992928 \\ -0.05938485 \\ 0.00000000 \end{bmatrix} \ (m)$$

$$^{R2}_{R2}\boldsymbol{J} = \begin{bmatrix} 0.00139985 & 0.00048233 & 0.00000000 \\ 0.00048233 & 0.00043426 & 0.00000000 \\ 0.00000000 & 0.00000000 & 0.00172741 \end{bmatrix} \ (kg\, m^2)$$

Left Link 2

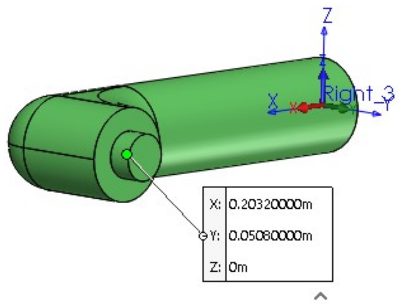


$$m_{L2} = 0.32122492 \quad (kg)$$

$$^{L2}_{L2}\boldsymbol{r}_{cm} = \begin{bmatrix} 0.01992928 \\ 0.05938485 \\ 0.00000000 \end{bmatrix} \ (m)$$

$$^{L2}_{L2}\boldsymbol{J} = \begin{bmatrix} 0.00139985 & -0.00048233 & 0.00000000 \\ -0.00048233 & 0.00043426 & 0.00000000 \\ 0.00000000 & 0.00000000 & 0.00172741 \end{bmatrix} \ (kg\, m^2$$

Right Link 3:

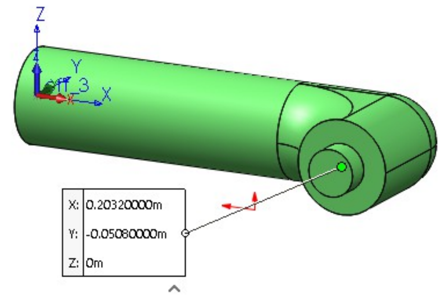


$$m_{R3} = 0.53126936 \ \ (kg)$$

$$ {}^{R3}_{R3}\boldsymbol{r}_{cm} = \begin{bmatrix} 0.12556172 \\ 0.00545976 \\ 0.00000000 \end{bmatrix} \ (m)$$

$$ {}^{R3}_{R3}\boldsymbol{J} = \begin{bmatrix} 0.00027263 & -0.00058392 & 0.00000000 \\ -0.00058392 & 0.01081142 & 0.00000000 \\ 0.00000000 & 0.00000000 & 0.01090959 \end{bmatrix} \ (kg\, m^2)$$

Left Link 3:

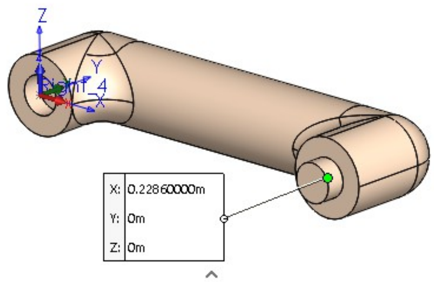


$$m_{L3} = 0.53126936 \ \ (kg)$$

$$ {}^{L3}_{L3}\boldsymbol{r}_{cm} = \begin{bmatrix} 0.12556172 \\ -0.00545976 \\ 0.00000000 \end{bmatrix} \ (m)$$

$$ {}^{L3}_{L3}\boldsymbol{J} = \begin{bmatrix} 0.00027263 & 0.00058392 & 0.00000000 \\ 0.00058392 & 0.01081142 & 0.00000000 \\ 0.00000000 & 0.00000000 & 0.01090959 \end{bmatrix} \ (kg\, m^2)$$

Right Link 4:

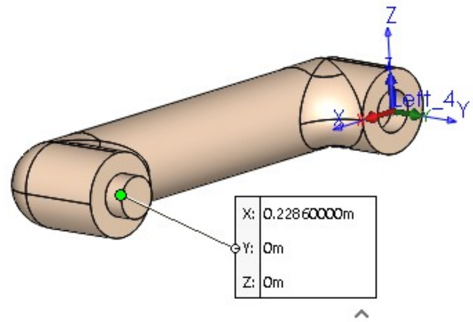


$$m_{R4} = 0.68159286 \ \ (kg)$$

$${}^{R4}_{R4}\boldsymbol{r}_{cm} = \begin{bmatrix} 0.11650147 \\ 0.04372769 \\ 0.00000000 \end{bmatrix} \ (m)$$

$${}^{R4}_{R4}\boldsymbol{J} = \begin{bmatrix} 0.00164808 & -0.00340665 & 0.00000000 \\ -0.00340665 & 0.01432027 & 0.00000000 \\ 0.00000000 & 0.00000000 & 0.01574865 \end{bmatrix} \ (kg\, m^2)$$

Left Link 4:

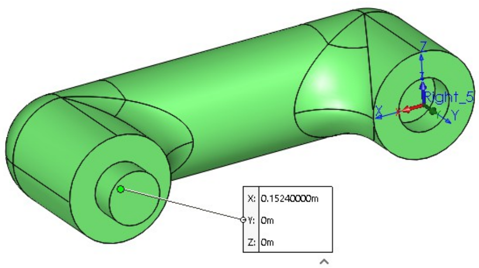


$$m_{L4} = 0.68159286 \ \ (kg)$$

$${}^{L4}_{L4}\boldsymbol{r}_{cm} = \begin{bmatrix} 0.11650147 \\ -0.04372769 \\ 0.00000000 \end{bmatrix} \ (m)$$

$${}^{L4}_{L4}\boldsymbol{J} = \begin{bmatrix} 0.00164808 & 0.00340665 & 0.00000000 \\ 0.00340665 & 0.01432027 & 0.00000000 \\ 0.00000000 & 0.00000000 & 0.01574865 \end{bmatrix} \ (kg\, m^2)$$

Right Link 5:

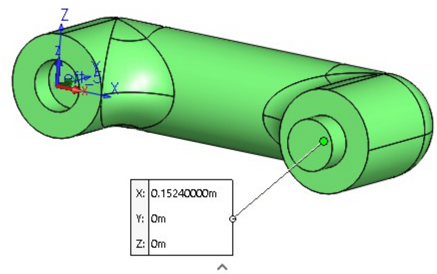


$$m_{R5} = 0.52405953 \quad (kg)$$

$$ {}^{R5}_{R5}\boldsymbol{r}_{cm} = \begin{bmatrix} 0.07810882 \\ -0.04160174 \\ 0.00000000 \end{bmatrix} \quad (m)$$

$$ {}^{R5}_{R5}\boldsymbol{J} = \begin{bmatrix} 0.00119073 & 0.00166130 & 0.00000000 \\ 0.00166130 & 0.00523181 & 0.00000000 \\ 0.00000000 & 0.00000000 & 0.00625366 \end{bmatrix} \quad (kg\, m^2)$$

Left Link 5:

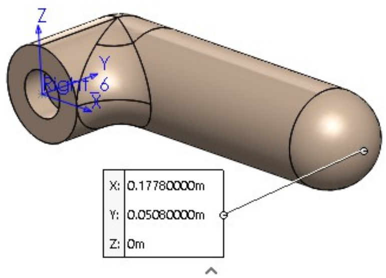


$$m_{R5} = 0.52405953 \quad (kg)$$

$$ {}^{R5}_{R5}\boldsymbol{r}_{cm} = \begin{bmatrix} 0.07810882 \\ 0.04160174 \\ 0.00000000 \end{bmatrix} \quad (m)$$

$$ {}^{R5}_{R5}\boldsymbol{J} = \begin{bmatrix} 0.00119073 & -0.00166130 & 0.00000000 \\ -0.00166130 & 0.00523181 & 0.00000000 \\ 0.00000000 & 0.00000000 & 0.00625366 \end{bmatrix} \quad (kg\, m^2)$$

Right Link 6:

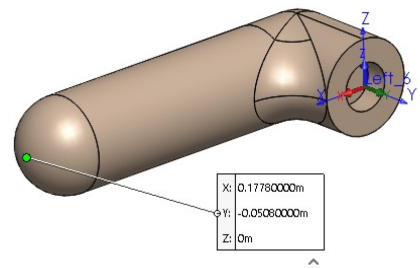


$$m_{R6} = 0.44800661 \quad (kg)$$

$$ {}^{R6}_{R6}\boldsymbol{r}_{cm} = \begin{bmatrix} 0.06557409 \\ 0.04616442 \\ 0.00000000 \end{bmatrix} \quad (m)$$

$$ {}^{R6}_{R6}\boldsymbol{J} = \begin{bmatrix} 0.00115148 & -0.00149053 & 0.00000000 \\ -0.00149053 & 0.00344884 & 0.00000000 \\ 0.00000000 & 0.00000000 & 0.00445655 \end{bmatrix} \quad (kg\, m^2)$$

Left Link 6:



$$m_{L6} = 0.44800661 \quad (kg)$$

$$ {}^{L6}_{L6}\boldsymbol{r}_{cm} = \begin{bmatrix} 0.06557409 \\ -0.04616442 \\ 0.00000000 \end{bmatrix} \quad (m)$$

$$ {}^{L6}_{L6}\boldsymbol{J} = \begin{bmatrix} 0.00115148 & 0.00149053 & 0.00000000 \\ 0.00149053 & 0.00344884 & 0.00000000 \\ 0.00000000 & 0.00000000 & 0.00445655 \end{bmatrix} \quad (kg\, m^2)$$