

# Application Guide

## How to design for higher payloads

Version 1.0

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# 1 Introduction

This document is an application guide to the UR10e [User Manual](#), and will address how to use the updated payload curve to assess the feasibility of applications given specific payload cases.

This guide will demonstrate best practices for dealing with high payloads and processes to optimize performance. The example application will cover precise calculation of payload, effects of restricting tool flange orientation, and how to utilize the payload curve during the design process. Comparatively, payloads falling within the shaded region can run with full motion parameters.

This guide will also show how to setup the Safety System to constrain the motion profile with the Tool Direction limit. This and other best practice features are vital during setup.

The specific example used for the entirety of this guide will be a typical palletizing routine. Motion will be constrained so there will be no rotation about the tool flange X or Y axes. The example application is defined in **Section 2**.

**Note: The reference application was studied using the new UR10e robot running PolyScope version 5.11. (Manufacture date 05/2021).**

## 1.1 Glossary of terms used

### 1.1.1 Center of Gravity (CoG):

CoG is a point of an object where the distribution of weight is equal in all directions. The location of the center of gravity is the combined offset vector from the robot's tool flange of the payload.

### 1.1.2 Tool Center Point (TCP):

The reference coordinate system, typically referenced to the tool flange, that is used to define where in space the robot moves.

### 1.1.3 Moment of Inertia (MOI):

MOI is the resistance of a body to rotate about an axis.

### 1.1.4 Coordinate Frames:

Two three-dimensional coordinate systems are referenced in this document tool frame and the base or world frame. The coordinate frame is used to reference position and orientation of objects in space.

### 1.1.5 Tool Frame:

The default coordinate frame aligned to the robot's face plate or tool flange.

### 1.1.6 Robot Base Frame:

The default coordinate frame with the origin at the center of the base. The robot is always mounted at coordinate [0, 0, 0] relative to the base frame.

## 2 Application Setup

In high payload applications, accurate tooling and payload data is key to the performance of an application. Best practices are to define the TCP, Payload, and MOI for each load case encountered during the process. As a starting point, an empty end-of-arm-tool (EOAT) is considered the default payload, and any multitude of combined part loads would require individual assignments (i.e. part in gripper #1 but not gripper #2, part in gripper #2 but not gripper #1). Entering incorrect data can produce joint deviations which result in inadvertent protective stops and other motion related errors.

### 2.1 TCP

Section 24.2 of the User Manual describes the process of defining and creating a TCP. Each TCP contains a translation and a rotation relative to the center of the tool output flange. It is advised to have a unique TCP for the application and not directly reference the default [0,0,0], [0,0,0]. A benefit of setting the TCP is that you can automatically adjust your application if your tool is remounted, bent, or replaced, just by reteaching the TCP offset.

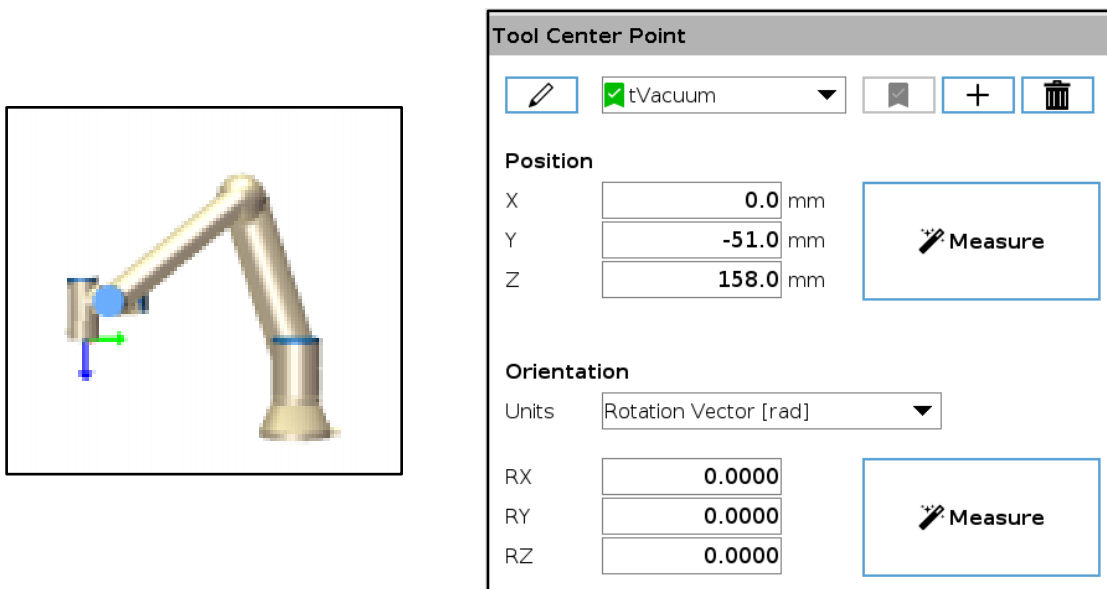


FIGURE 1 – TCP

### 2.2 Center of Gravity (CoG) and Payload

For best performance, like the previous section, accuracy of values entered for Payload and Center of Gravity (CoG) offset impact performance. PolyScope software has several features that aid in generating this data. For example, if a value for payload is entered above the robot's rated maximum, a pop-up warning will appear. Additionally, with e-Series robots the use of the payload wizard can aid in defining this data. For more information on the payload wizard, reference Section 24.3 of the User Manual. An example from PolyScope is shown in [FIGURE 2](#). For the most accurate data, it is advised to use a 3D modeling software. For the palletizing example, [Section 5](#), material properties were assigned to the assembly prior to generating the data output.

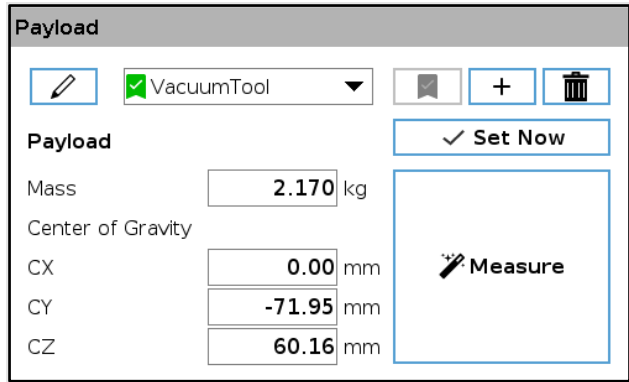


FIGURE 2 – PAYLOAD & CENTER OF GRAVITY

For applications where payloads change, this data needs to be defined for each scenario. In these cases, the “Set Payload” command is added to the PolyScope program tree, reference FIGURE 3. Additional information for this command can be found in Section 23.10.14. of the User Manual.

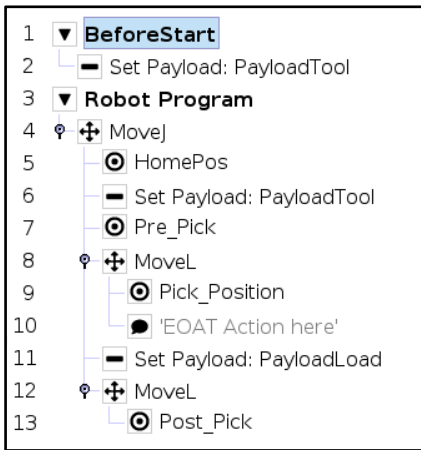


FIGURE 3 – EXAMPLE PROGRAM WITH SET PAYLOAD COMMAND

2.3 Moment of Inertia (MOI)

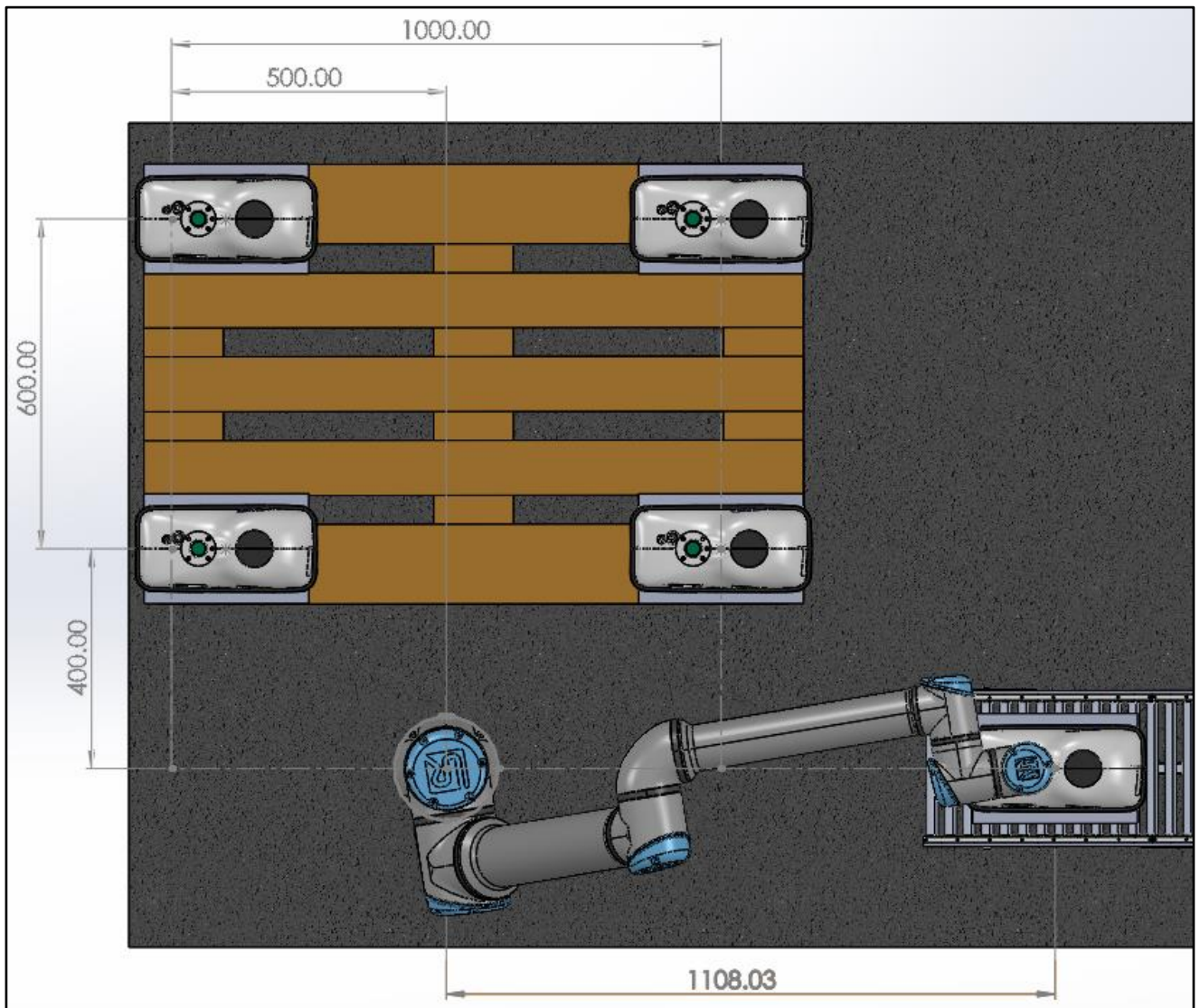
The inertia of the payload is specified in the coordinate system aligned to the tool flange with the origin at the Center of Gravity (CoG). The default inertia is calculated as the inertia of a sphere with the user specified mass, and a mass density of 1g/cm<sup>3</sup>. A custom inertia setting can be set by selecting **Use custom Inertia Matrix**. Tap the fields IXX, IYY, IZZ, IXZ, IYZ to set the inertia for the selected Payload, using base units of kg\*m<sup>2</sup>, as shown in FIGURE 4.

Inertia (kg m <sup>2</sup> )			
	X	Y	Z
<input checked="" type="checkbox"/> Use custom Inertia Matrix			
X	0.018259	0.000000	0.000000
Y	0.000000	0.005451	0.000000
Z	0.000000	0.000000	0.019717


FIGURE 4 - POLYSCOPE INPUT FOR CUSTOM INERTIA MATRIX

### 3 Example Application

For the example application a typical palletizing routine will be used. The mechanical layout used for testing is shown in **FIGURE 5**. In addition, motions and setup parameters are listed in **TABLE 1**. Additional information on tooling, payloads and system set up are discussed in subsequent sections.



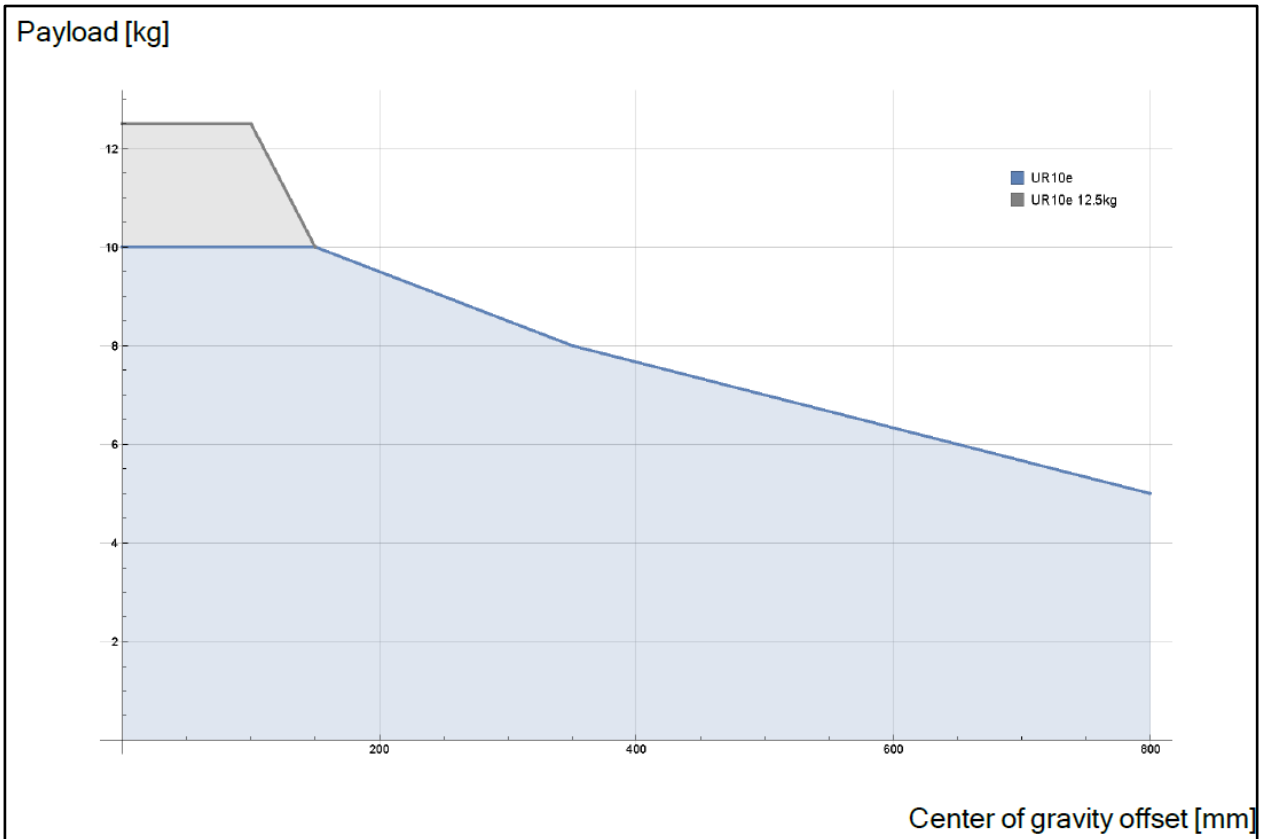
**FIGURE 5 – PALLETIZING EXAMPLE LAYOUT**

	X [mm]	Y [mm]	Z [mm]	Rx [deg]	Ry [deg]	Rz [deg]																											
<b>Pick</b>	1108,03	0	200	-180	0	-90																											
<b>Corner 1</b>	-500	1000	-200	-180	0	0																											
<b>Corner 2</b>	-500	400	-200	-180	0	0																											
<b>Corner 3</b>	500	400	-200	-180	0	0																											
<b>Corner 4</b>	500	1000	-200	-180	0	0																											
<b>Pallet Pattern</b>	4x4 (16 cycles); 1 layer																																
	<b>Linear Moves</b>			<b>Joint Moves</b>																													
<b>Speed</b>	2,000 mm/s			120 °/s																													
<b>Acceleration</b>	1,500 mm/s <sup>2</sup>			240°/s <sup>2</sup>																													
<b>Approach offset</b>	125mm																																
<b>Dwell at Pick/ Place</b>	1.00s																																
<b>Robot Limit Safety Settings</b>	<p><b>! DANGER</b></p> <p>Use of Safety Configuration parameters different from those defined by the risk assessment can result in hazards that are not reasonably eliminated or risks that are not sufficiently reduced.</p> <p><input checked="" type="radio"/> Factory Presets</p> <p style="text-align: center;"> <span>Most Restricted</span> <input type="range"/> <span>Least Restricted</span> </p> <p><input type="radio"/> Custom</p> <table border="1"> <thead> <tr> <th>Limit</th> <th>Normal</th> <th>Reduced</th> </tr> </thead> <tbody> <tr> <td>Power</td> <td>300 W</td> <td>200 W</td> </tr> <tr> <td>Momentum</td> <td>25.0 kg m/s</td> <td>10.0 kg m/s</td> </tr> <tr> <td>Stopping Time</td> <td>400 ms</td> <td>300 ms</td> </tr> <tr> <td>Stopping Distance</td> <td>500 mm</td> <td>300 mm</td> </tr> <tr> <td>Tool Speed</td> <td>1500 mm/s</td> <td>750 mm/s</td> </tr> <tr> <td>Tool Force</td> <td>150.0 N</td> <td>120.0 N</td> </tr> <tr> <td>Elbow Speed</td> <td>1500 mm/s</td> <td>750 mm/s</td> </tr> <tr> <td>Elbow Force</td> <td>150.0 N</td> <td>120.0 N</td> </tr> </tbody> </table> 						Limit	Normal	Reduced	Power	300 W	200 W	Momentum	25.0 kg m/s	10.0 kg m/s	Stopping Time	400 ms	300 ms	Stopping Distance	500 mm	300 mm	Tool Speed	1500 mm/s	750 mm/s	Tool Force	150.0 N	120.0 N	Elbow Speed	1500 mm/s	750 mm/s	Elbow Force	150.0 N	120.0 N
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**TABLE 1 – PALLETIZING EXAMPLE MOTION CRITERIA**

### 3.1 How to Utilize the Payload Curve

The payload curve in **FIGURE 6** shows the graphical boundary of the CoG offset compared to the maximum allowed payload. Inside of the shaded boundary allows for unconstrained robot motion, that is the robot can be expected to perform at its rated speed and acceleration. Comparatively, robot motion outside of this boundary will be subject to automatic reductions in robot speed and acceleration. The graph highlights the increased payload rating up to 12.5kg on the UR10e.



**FIGURE 6 – PAYLOAD CURVE FROM UR10E USER MANUAL**

#### 3.1.1 Calculating the Center of Gravity offset

The center of gravity (CoG) location can be calculated in several ways. Typically, this is done via a 3D modeling program, such as SolidWorks, or with the native payload wizard from PolyScope. The Payload Wizard process is outlined in Section 24.3.3 of the User Manual. However, in some cases, utilizing the wizard with larger payloads is not feasible. For those instances, the CoG location and other payload should be set as close as possible to the exact scenario that the robot will encounter.



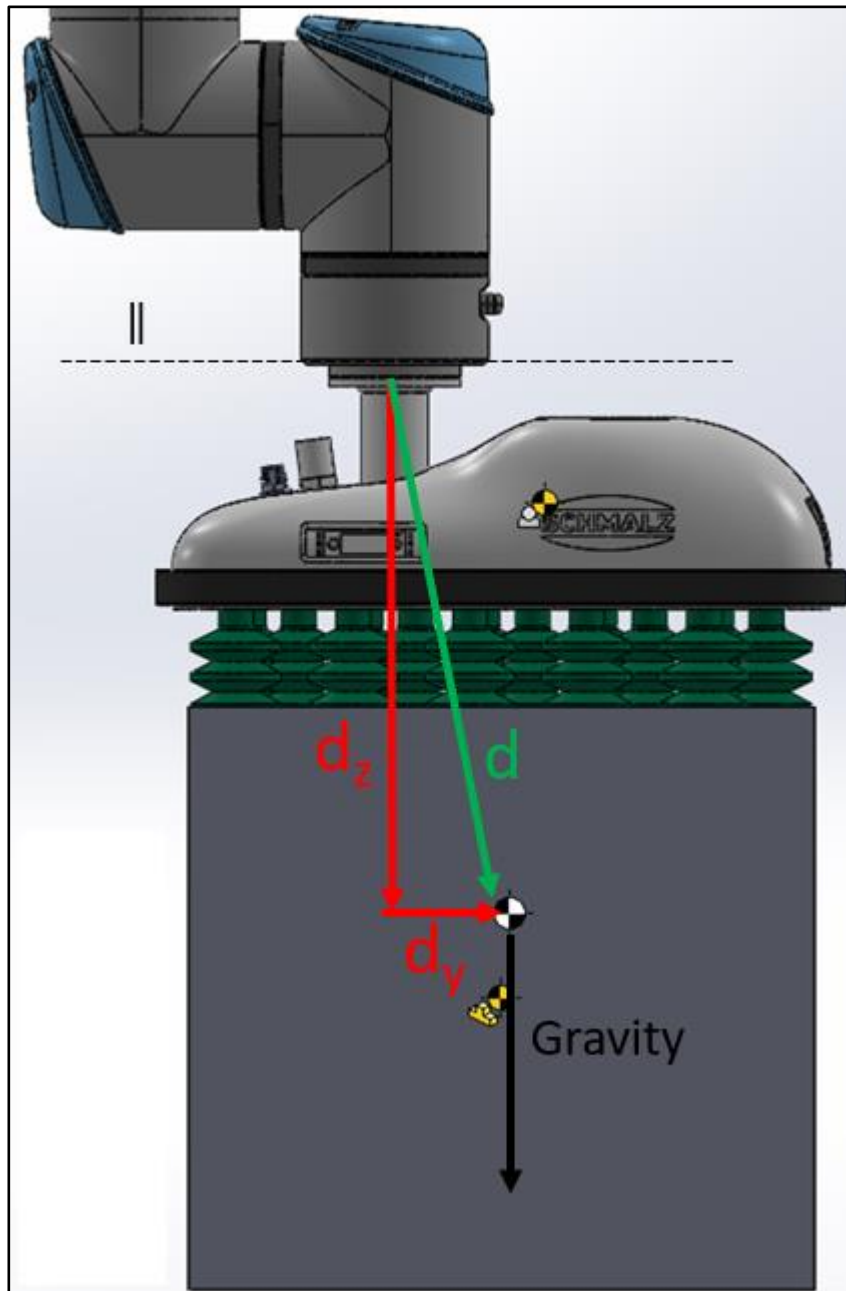
### 3.1.2 How to Generate Payload Data in SolidWorks

In this use case, we utilize SolidWorks Mass Properties evaluation tool to generate the data. **TABLE 2** shows the mass properties of the tool and the payload independently. The tool mass properties are given from the supplier’s website. The part is a generic rectangle measuring 200mm x 300mm x 280mm.

Palletizing Application example UR10e – 12.5kg				
<b>Total Payload</b>	12.5 kg			
<b>Tool Load</b>	2.17 kg			
	CoG location (from Tool Flange)			
	X = 0mm Y = -71.95mm Z = 60.16mm			
	MOI			
	I	X	Y	Z
	X	0.01826	0	0
	Y	0	0.0055	0
	Z	0	0	0.0197
<b>Part</b>	10.33 kg			
	CoG location (At volumetric center)			
	X = 0mm Y = 0mm Z = 0mm			
	MOI (kg*m <sup>2</sup> )			
	I	X	Y	Z
	X	0.1019	0	0
	Y	0	0.1120	0
	Z	0	0	0.1450

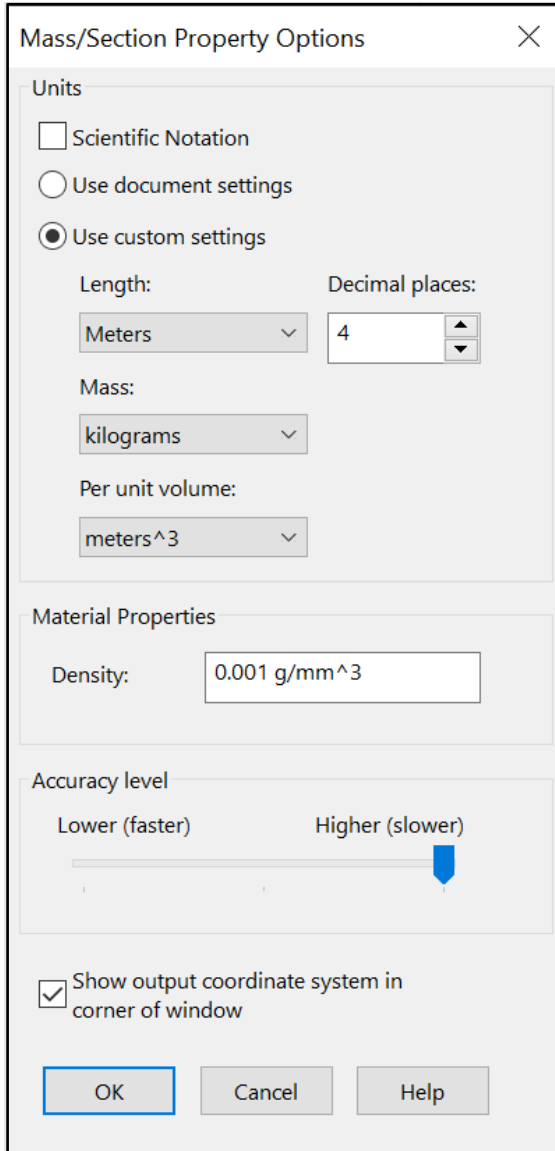
**TABLE 2 – MOI DATA FOR PALLETIZING EXAMPLE**

Shown in **FIGURE 7** is a 3D model generated from SolidWorks. The CoG locations for each individual component indicated by the yellow and black fiducials. The CoG location for the combined components is referenced by the white and black fiducial. Also noted is the direction of gravity.

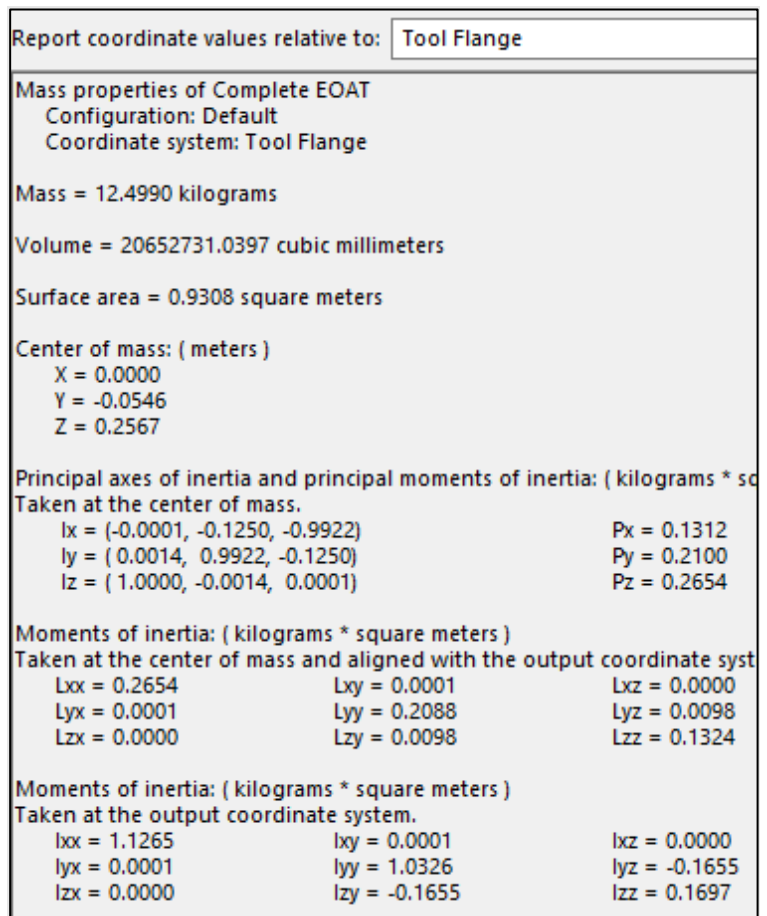


**FIGURE 7 – MODEL OF TOOLING AND PAYLOAD CoG LOCATION FROM SOLIDWORKS**

The associated mass properties can be calculated directly through the Mass Properties evaluation tool. Once units of measure in the software are configured, the values generated are used for payload settings. The MOI settings are accessed via the “Options...” button in the main window, shown in [FIGURE 8](#). Once the units are defined, the mass properties for the model are shown in the main window, see [FIGURE 9](#). This data can be directly entered into the inertia matrix for that given load case.

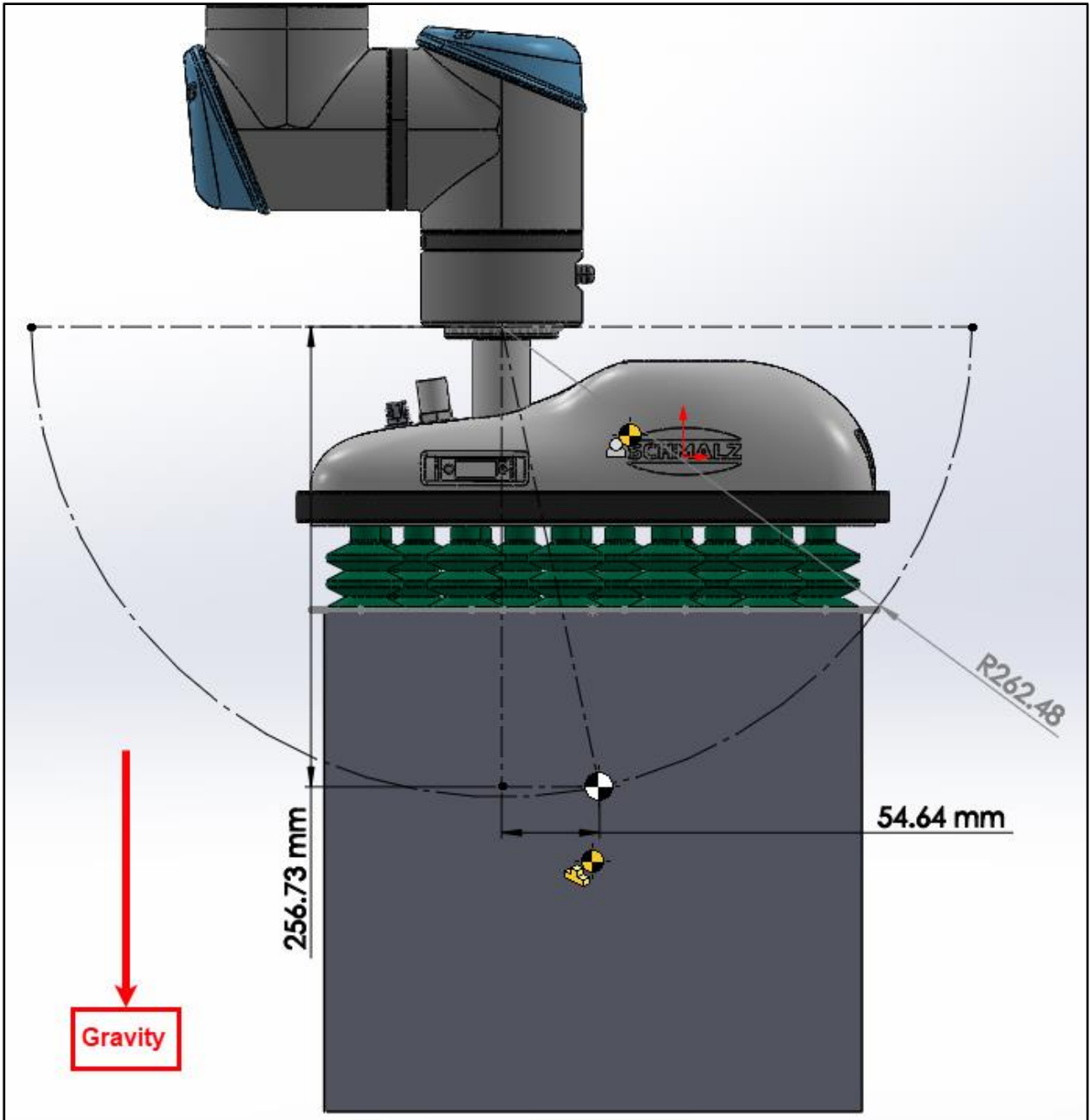


**FIGURE 8 – OPTIONS SETTINGS FOR CORRECT UNITS**



**FIGURE 9 – MODEL MASS PROPERTIES EVALUATION**

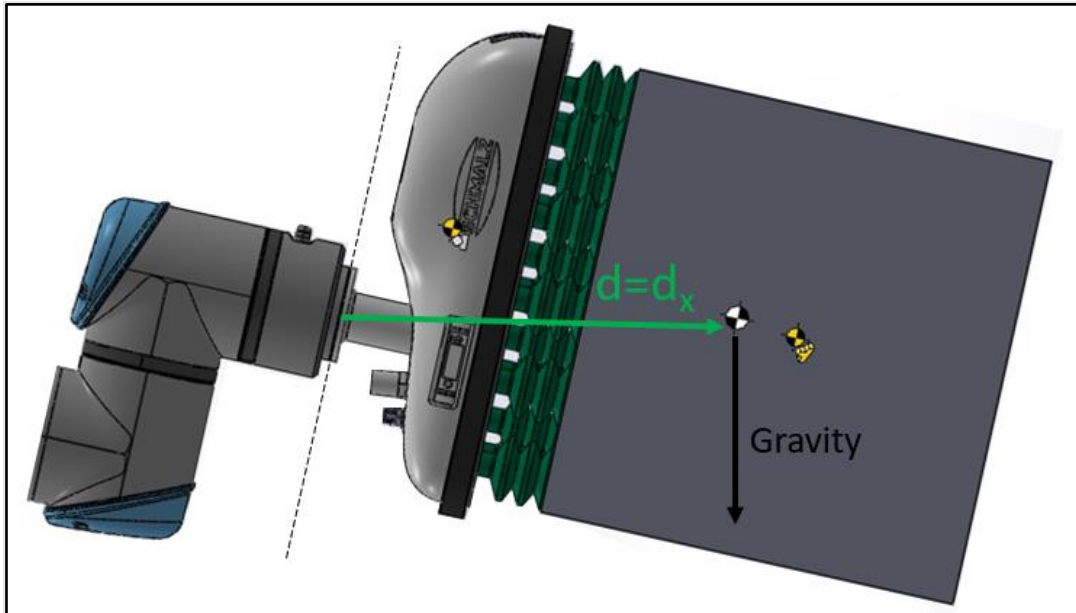
From **FIGURE 10** the CoG location is located at **(0, -0.0546, 0.2567)** meters in the Tool Flange coordinate system. These values are inserted into a sketch as the vertical ( $d_z$ ) and horizontal ( $d_y$ ) CoG components shown in **FIGURE 7**. The resultant vector is shown as a radius from the tool flange origin (262.48mm).



**FIGURE 10 – CoG LOCATION SKETCHED ONTO MODEL**

### 3.2 Restricting Tool Flange Orientation

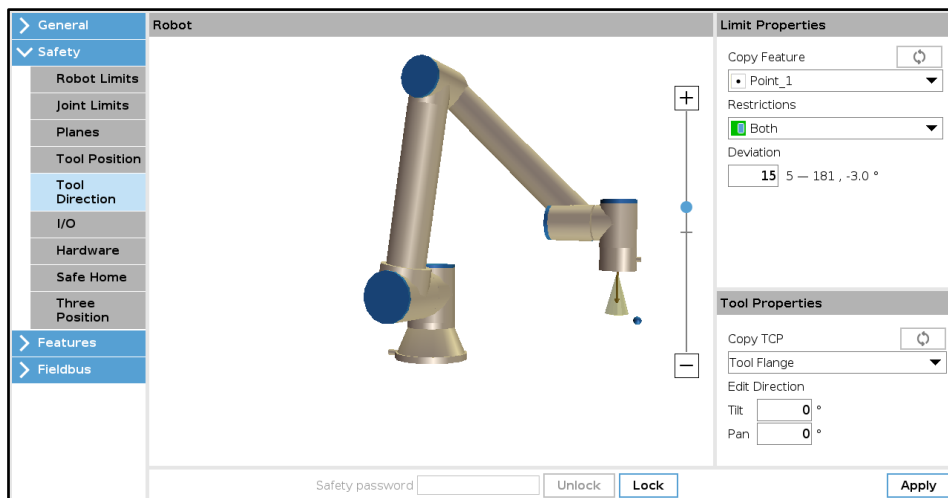
In this section, tool flange orientation and the effects of restricting this orientation are described. The goal when designing for higher payloads is to limit the torque about the origin of the tool flange. As a result, a smaller perpendicular CoG offset in relation to gravity decreases this value. In **FIGURE 11**, the maximum torque acting upon the tool flange is shown with this given load case. If this case is plotted onto the payload curve, the payload would be outside of the shaded region.



**FIGURE 11 – COG LOCATION SKETCHED ONTO MODEL**

#### 3.2.1 Tool Direction Feature

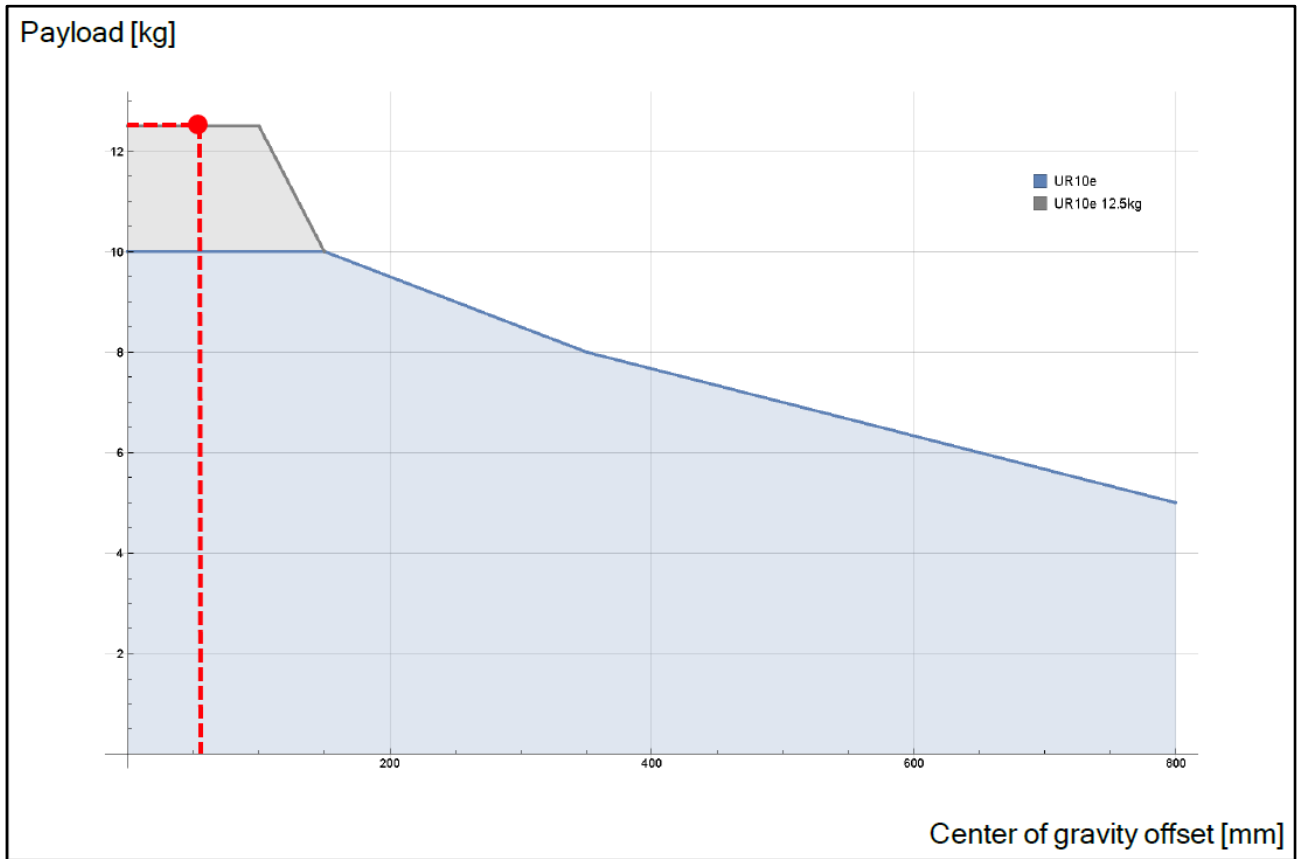
The tool direction feature is used to restrict angles of the tool frame. As part of the safety configuration, it is advised to apply these configurations prior to programming. Once properly configured this feature prevents inadvertent stops or faults. For more information on this command, see Section 21.15 of the User Manual. In this example, we limit the pan and tilt of the tool flange to  $\pm 15$  degrees, as shown in **FIGURE 12**.



**FIGURE 12 – TOOL DIRECTION CONFIGURATION**

### 3.3 How to Reference Payload Curve with of CoG offset

Having the vertical and horizontal components of the CoG offset location, we can now apply them to the payload chart. For the example application, the tool flange will remain in the orientation shown in **FIGURE 10** based on the conclusion outlined in **Section 3.1.2**. Knowing this, the component of the CoG offset location that is perpendicular to gravity is Y component (54.64mm). Plotting the values of 12.5kg and 54.64mm onto the payload curve shows the application remains within the shaded region of the graph.



**FIGURE 13 – MAXIMUM PAYLOAD FOR HORIZONTAL COMPONENT OF COMBINED PAYLOAD**

### 3.4 Palletizing Application Results

In this section, the results of the simulated cycles are shown from the UR Offline Simulator tool. The UR Offline Simulator can be found on the [UR support site](#). The safety settings and criteria for motion are referenced in **TABLE 1**. The benchmark case uses the payload defined in **Section 3**. The results from the simulation are outlined in **TABLE 3**.

Palletizing UR10e	Benchmark case																
<b>Total Payload</b>	12.5 kg																
<b>Tool Load</b>	2.17 kg CoG location (from Tool Flange) X = 0mm Y = -71.95mm Z = 60.16mm MOI <table border="1" data-bbox="612 770 1187 931"> <thead> <tr> <th>I</th> <th>X</th> <th>Y</th> <th>Z</th> </tr> </thead> <tbody> <tr> <td>X</td> <td>0.01826</td> <td>0</td> <td>0</td> </tr> <tr> <td>Y</td> <td>0</td> <td>0.0055</td> <td>0</td> </tr> <tr> <td>Z</td> <td>0</td> <td>0</td> <td>0.0197</td> </tr> </tbody> </table>	I	X	Y	Z	X	0.01826	0	0	Y	0	0.0055	0	Z	0	0	0.0197
I	X	Y	Z														
X	0.01826	0	0														
Y	0	0.0055	0														
Z	0	0	0.0197														
<b>Combined Load (Tool and Part)</b>	12.5 kg CoG location X = 0mm Y = -54.64mm Z = 256.73mm Horizontal CoG component: <b>54.64mm</b> MOI <table border="1" data-bbox="612 1128 1187 1290"> <thead> <tr> <th>I</th> <th>X</th> <th>Y</th> <th>Z</th> </tr> </thead> <tbody> <tr> <td>X</td> <td>0.2654</td> <td>0</td> <td>0</td> </tr> <tr> <td>Y</td> <td>0</td> <td>0.2088</td> <td>0</td> </tr> <tr> <td>Z</td> <td>0</td> <td>0</td> <td>0.1324</td> </tr> </tbody> </table>	I	X	Y	Z	X	0.2654	0	0	Y	0	0.2088	0	Z	0	0	0.1324
I	X	Y	Z														
X	0.2654	0	0														
Y	0	0.2088	0														
Z	0	0	0.1324														
<b>Capacity</b>	7.9 cases/ minute ~7.594 seconds/ cycle																

**TABLE 3 – PALLETIZING EXAMPLE SIMULATION RESULTS**

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