Application Guide

How to design for higher payloads

Version 2.1

Revision Notes:

Version 1.0	Initial Release	3/2022
Version 2.0	Update with UR20/UR30 and increased payloads	9/2024
Version 2.1	Included Payload Transition Time	11/2024
Version 2.2	To Include Tool Wrench Limit	

1 Introduction

This document is an application guide complimenting the UR10e, UR20 & UR30 User Manual(s). This guide will address the changes to our published payload curves and how to utilize them when assessing applications for 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 3.**

Note: The reference application was studied using the 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/product loads 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 and possibly inadvertent stop conditions, or 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.

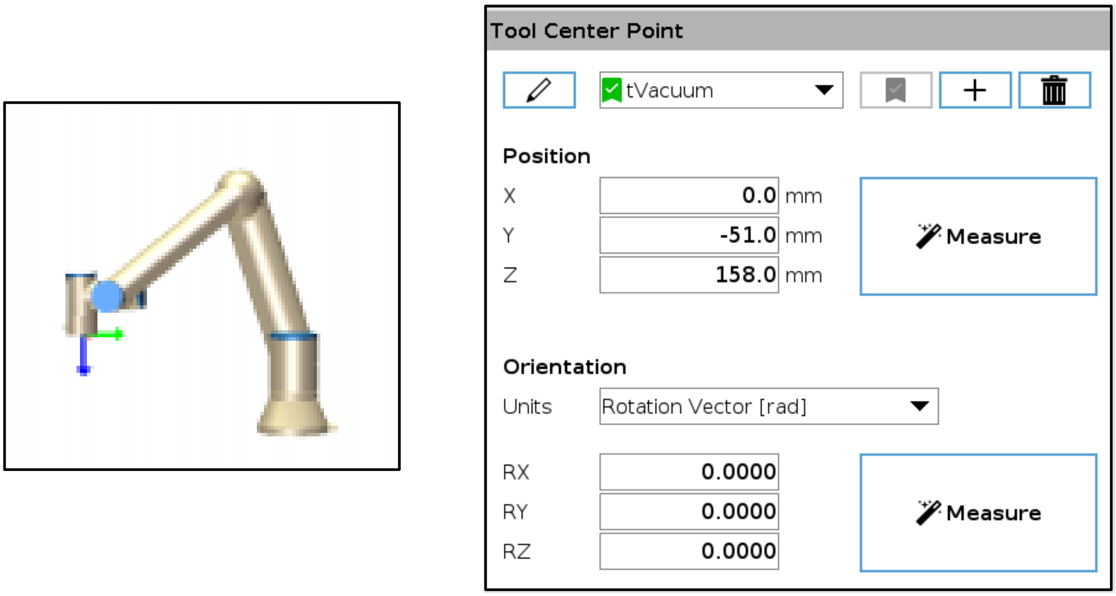


FIGURE 1 – TCP

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.

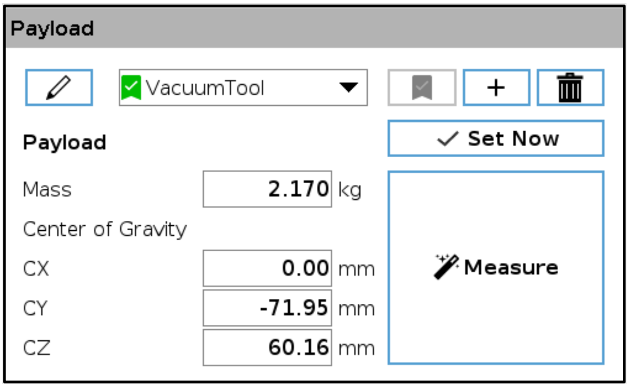


FIGURE 2 – PAYLOAD & CENTER OF GRAVITY

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.

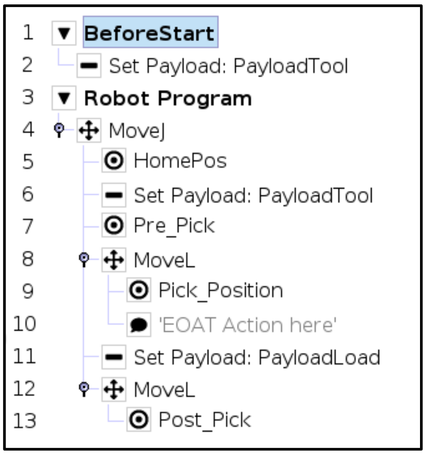


Image to be updated --> in the latest SW version, in the Set Payload command the transition time appears

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/cm3. 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^2, as shown in FIGURE 4.

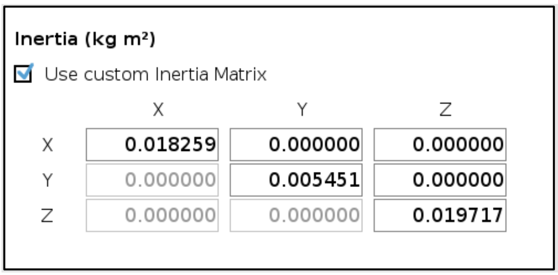


FIGURE 4 - POLYSCOPE INPUT FOR CUSTOM INERTIA MATRIX

2.4 Payload Transition Time

Starting with Polyscope v5.15, the "set_target_payload()" command includes an optional argument to adjust the transition time [s] of the target payload. When configured, the time variable ramps payload until reaching the target value. The effect is a smooth transition that can be observed visually, or through analyzing arm data. We suggest using this added functionality for large payload changes. For example, grasping or ungrasping a workpiece near capacity of the robot arm. Please note, the robot can continue executing the program during this transition, which eliminates the need to wait or sleep. Additionally, it is important to execute the set payload with a transition time command before activating your tool.

Usage: set_target_payload(m, cog, inertia=[0, 0, 0, 0, 0, 0], transition_time=0)

- A transition time of 0 applies the payload instantly. This can lead to a stop condition due to the sudden change in payload.
- By setting a non-zero transition time **(typically between 0.3-2 seconds)**, the robot gradually increments payload. The result is a smooth transition to the new load condition.

Choosing the appropriate transition time depends on the specific application and requires some practical judgment. For example, picking up a box with suction cups may need a longer transition time due to material deformation, while a mechanical gripper might require less time since the system is rigid.

2.4.1 Procedure for Tuning Transition Time:

When setting the transition time variable:

1. **Start with a Higher Value:** Set a higher transition time initially. If this time is too long, the robot may move too slowly, potentially triggering a stop condition.
2. **Gradually Decrease the Value:** Reduce the transition time incrementally (by 0.1-0.2 seconds) until the robot can successfully lift the part without faulting.
3. **Fine-Tune the Value:** If the robot transitions to the target payload smoothly, try further reducing the transition time in small increments (0.1-0.2 seconds) until a stop condition. The stop condition provides your lower limit.
4. **Consider Robot Speed and Mode:** The optimal transition time may vary depending on the robot's speed. A robot moving at 70% speed will typically require a lower transition time compared to one moving at 10%. At higher speeds, the picking action occurs much faster thus requiring a faster payload application.
   Additionally, values may differ **between manual and automatic mode**, so further tuning might be necessary when switching from manual testing to automatic operation.
5. **Avoid High Accelerations while Payload is Ramping:** High accelerations before the target payload is reached can result in unintended stops. We suggest short (<100mm) "retract" or "approach" moves relative to the target position with reduced motion parameters. During this motion, the effect of incrementing payload is reduced. During the subsequent motion, you can increase the parameters to meet the requirements of your application.

In most cases, one value for transition time is enough to grasp various products. However, for some applications different parameters are needed. For those instances, refer to this article with best practices for identifying the transition time variable: Universal Robots - set_target_payload() – Transition Time (universal-robots.com)

2.4.2 Procedure for Handling Non-Rigid Containers:

When handling non-rigid containers (e.g. sacks, boxes … etc.) there are several aspects to consider while programming your application. Typically, the transition time variable is tuned based on the amount of deformation of the product.

For example, if there is variation in the load and it sometimes contacts the placement surface before reaching the target position, using an "Until Tool Contact" node to trigger the start of the transition time can aid in a smoother and quicker release. If the load is more uniform and deformation is uniform, using an intermediate position to trigger the transition time could be sufficient. Utilizing the transition time variable is effective when handling these types of loads. Below are methods for releasing these types of containers:

Using Until Tool Contact:

1. Embed the "Until Tool Contact" condition within a short (<100mm) approach move
2. Optional: Set the retract distance to 0mm
3. After contact, use the "Set Payload" command to a no-load condition using transition time (stating from 2s)
4. Resume motion to the target position
5. Insert a Tool Action to release the product

Without using Until Tool Contact:

1. Create a move with reduced motion parameters
2. Use the "Set Payload" command to trigger a no-load condition using transition time (stating from 2s)
3. Configure two robot positions with the first being where the load touches the placement surface, and the next being the placement position.
4. Insert a Tool Action to release the product

3 Example Application

In **Section 3**, an example palletizing routine is referenced. 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.

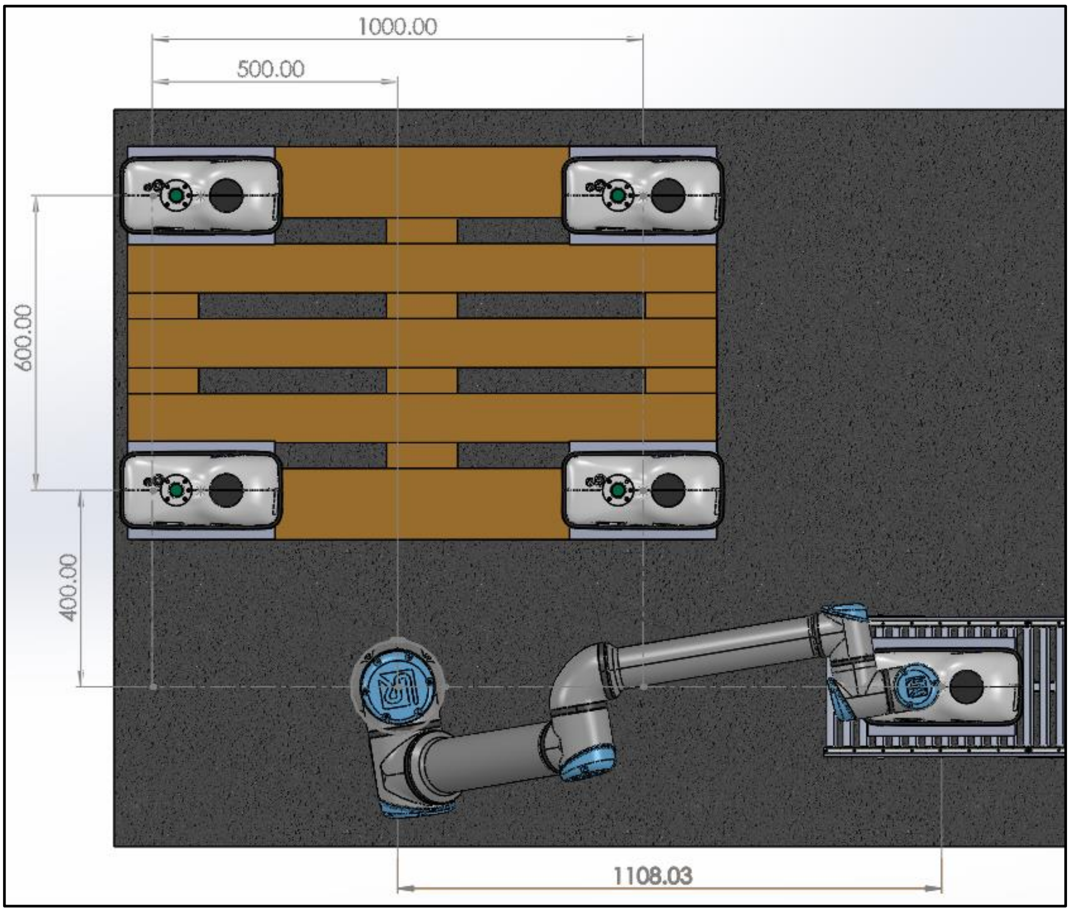


FIGURE 5 – PALLETIZING EXAMPLE LAYOUT

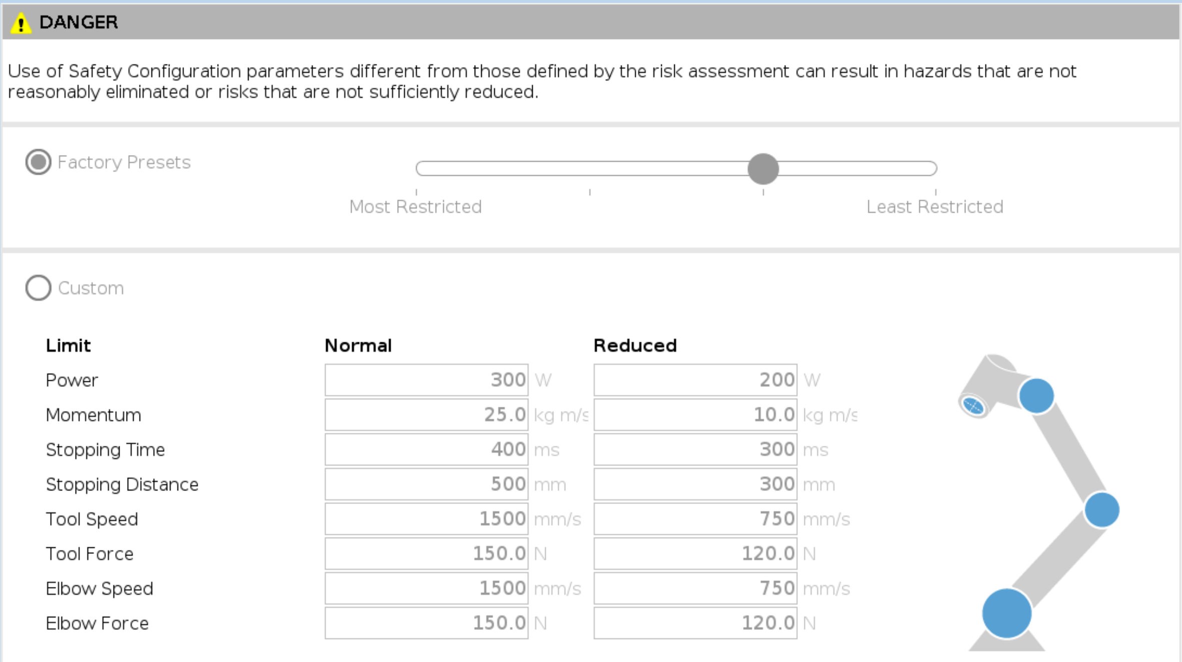
	X [mm]	Y [mm]	Z [mm]	Rx [deg]	Ry [deg]	Rz [deg]
Pick	1108,03	0	200	-180	0	-90
Corner 1	-500	1000	-200	-180	0	0
Corner 2	-500	400	-200	-180	0	0
Corner 3	500	400	-200	-180	0	0
Corner 4	500	1000	-200	-180	0	0
Pallet Pattern	4x4 (16 cycles); 1 layer					
	Linear Moves			**Joint Moves**		
Speed	2,000 mm/s			120 °/s		
Acceleration	1,500 mm/s^2			240°/s^2		
Approach offset	125mm					
Dwell at Pick/ Place	1.00s					
Robot Limit Safety Settings						

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 for the UR10e robot. Inside of the shaded boundary allows for unconstrained robot motion, or when the robot can be expected to perform at its rated speed and acceleration. Comparatively, robot motion outside of this boundary is subject to automatic reductions in speed and acceleration. If we review the updated payload curves for UR20 and UR30 in **FIGURE 7** and **FIGURE 8** respectively, the full performance region or limits for unconstrained motion are unchanged. Instead, the Expanded payload region increases payload capacity for Tool down motion.

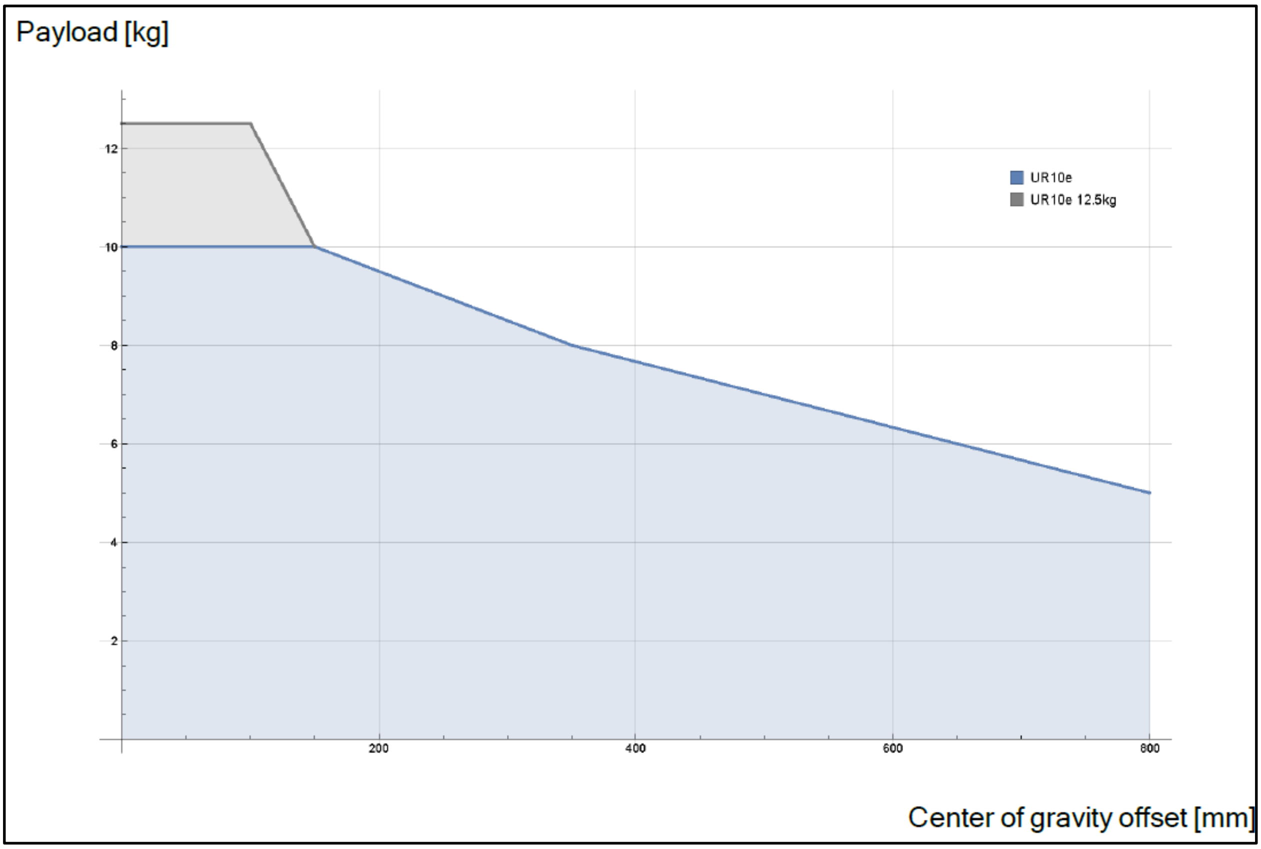


FIGURE 6 – PAYLOAD CURVE FROM UR10E USER MANUAL

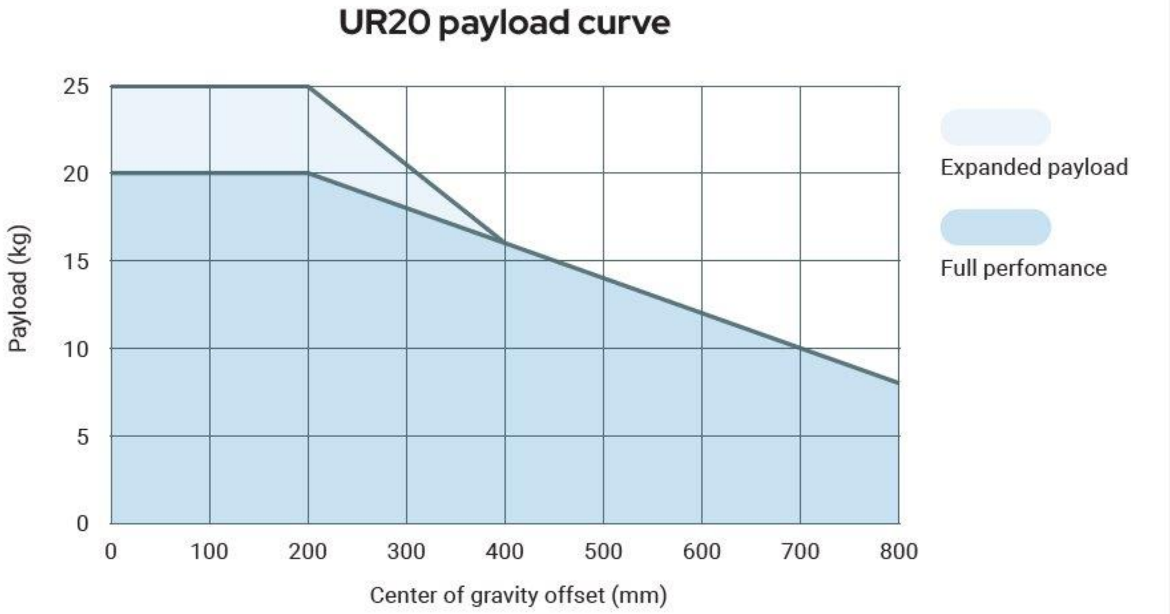


FIGURE 7 – PAYLOAD CURVE FROM UR20 USER MANUAL

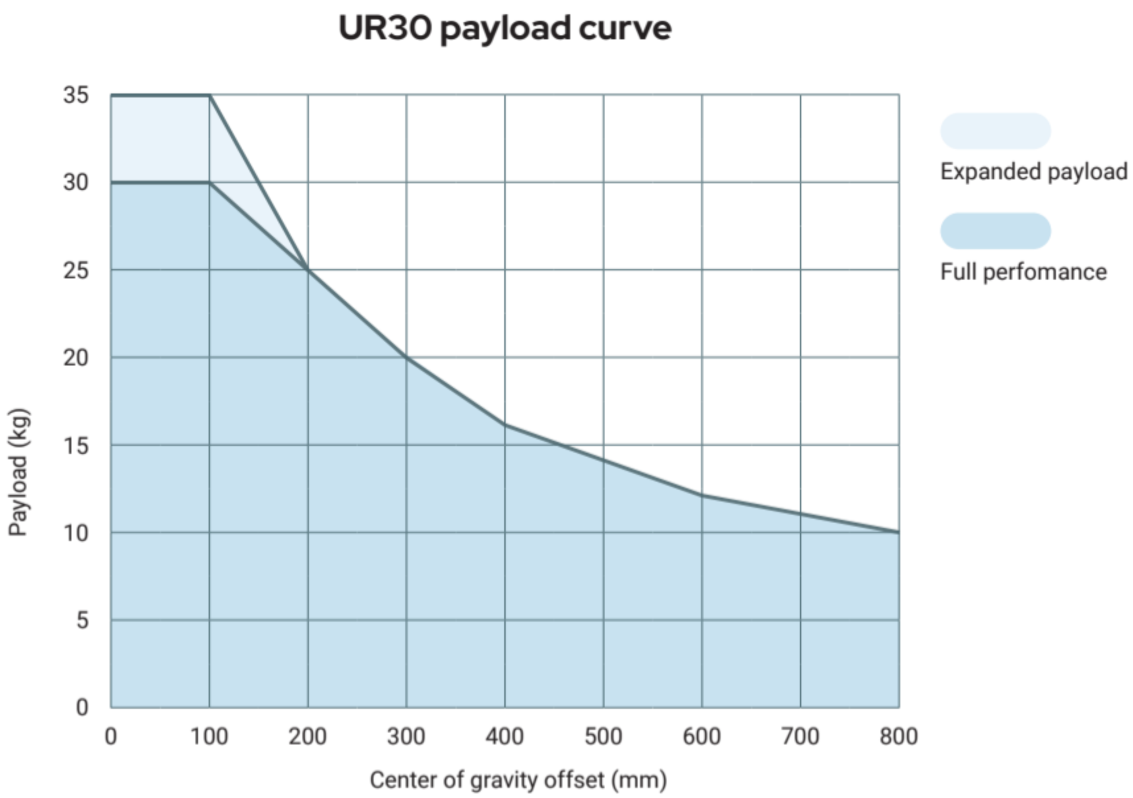


FIGURE 8 – PAYLOAD CURVE FROM UR30 USER MANUAL

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, utilizing a 3rd party modeling software to estimate a payload is an important skill to utilize for fringe applications.

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.

<table>
<tr><th colspan="2">Palletizing Application example UR10e – 12.5kg</th></tr>
<tr><td>Total Payload</td><td>12.5 kg</td></tr>
<tr><td>Tool Load</td><td>2.17 kg
CoG location (from Tool Flange)
X = 0mm Y = -71.95mm Z = 60.16mm
MOI
<table>
<tr><td>I</td><td>X</td><td>Y</td><td>Z</td></tr>
<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>
</table></td></tr>
<tr><td>Part</td><td>10.33 kg
CoG location (At volumetric center)
X = 0mm Y = 0mm Z = 0mm --> Update these coordinates for the part
MOI (kg*m^2)
<table>
<tr><td>I</td><td>X</td><td>Y</td><td>Z</td></tr>
<tr><td>X</td><td>0.1019</td><td>0</td><td>0</td></tr>
<tr><td>Y</td><td>0</td><td>0.1120</td><td>0</td></tr>
<tr><td>Z</td><td>0</td><td>0</td><td>0.1450</td></tr>
</table></td></tr>
</table>

TABLE 2 – MOI DATA FOR PALLETIZING EXAMPLE

Shown in FIGURE 9 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.

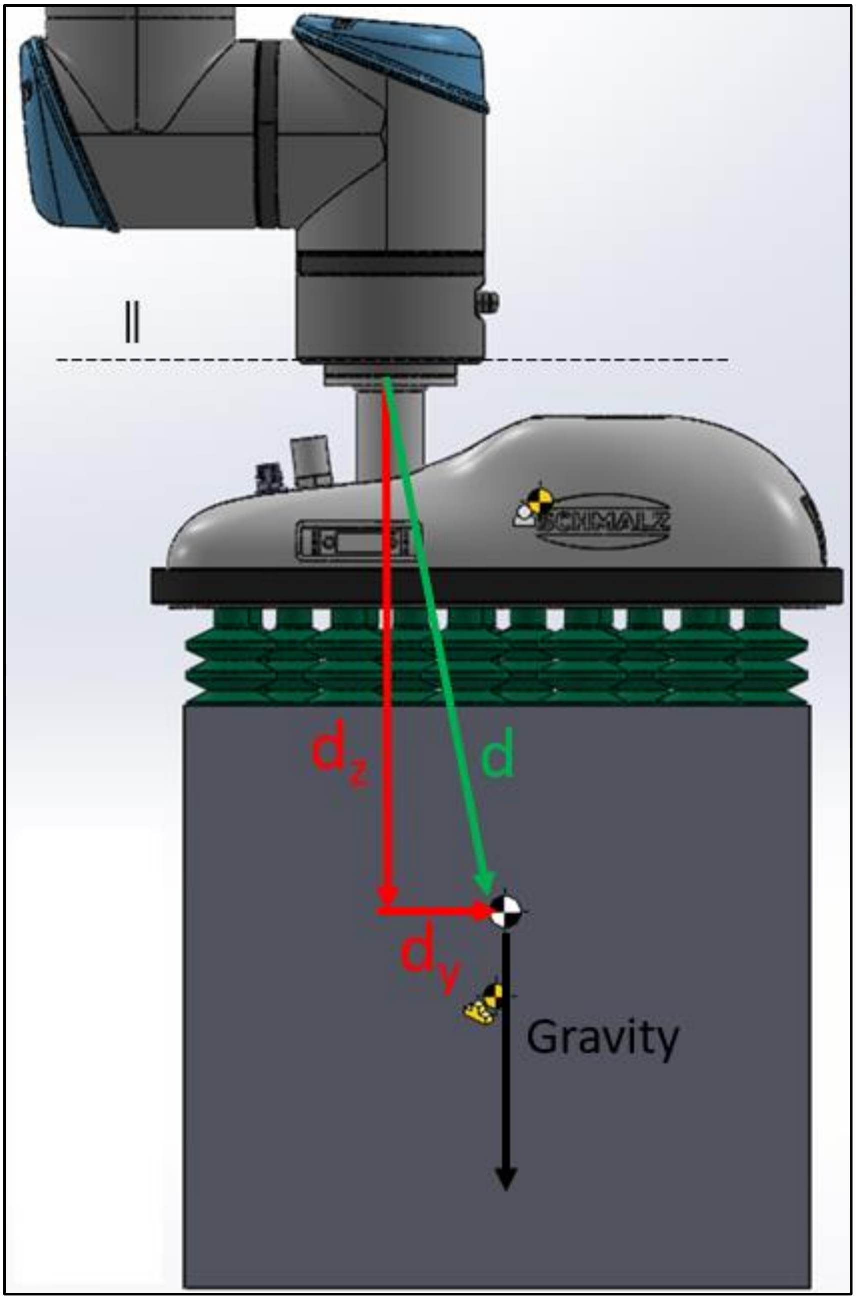


FIGURE 9 – MODEL OF TOOLING AND PAYLOAD COG LOCATION FROM SOLIDWORKS

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 10. Once the units are defined, the mass properties for the model are shown in the main window, see FIGURE 11. This data can be directly entered into the inertia matrix for that given load case.

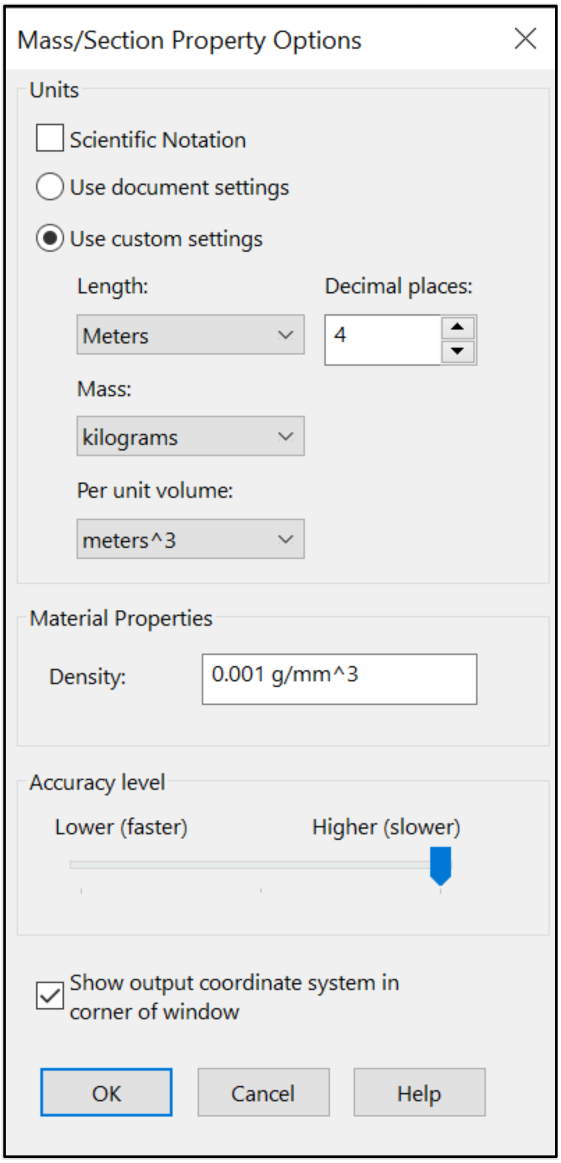


FIGURE 10 – OPTIONS SETTINGS FOR CORRECT UNITS

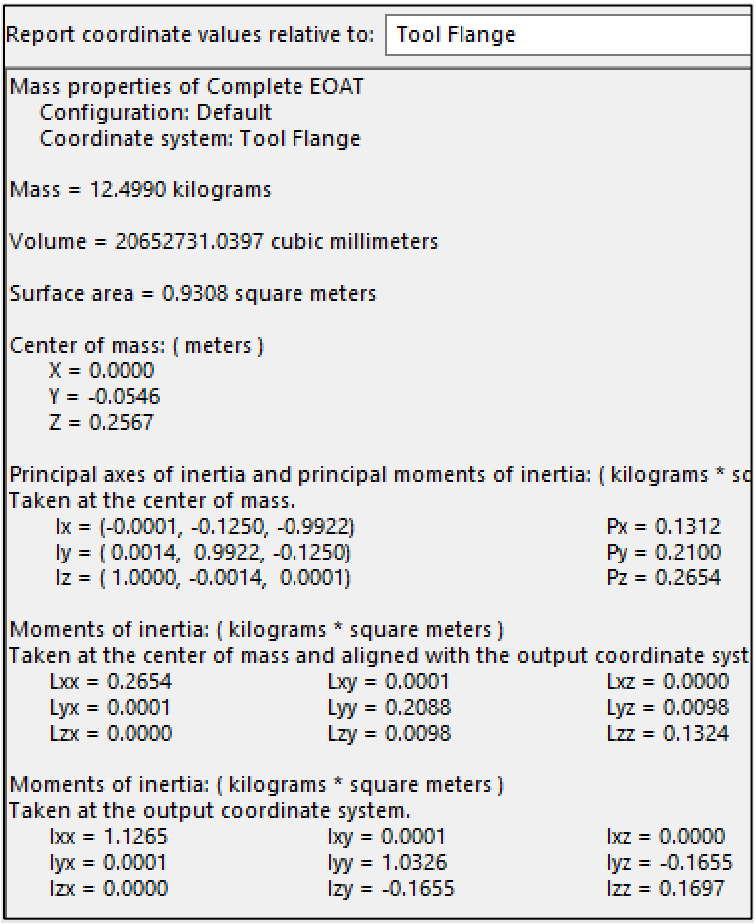


FIGURE 11 – MODEL MASS PROPERTIES EVALUATION

From FIGURE 12 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 9. The resultant vector is shown as a radius from the tool flange origin (262.48mm).

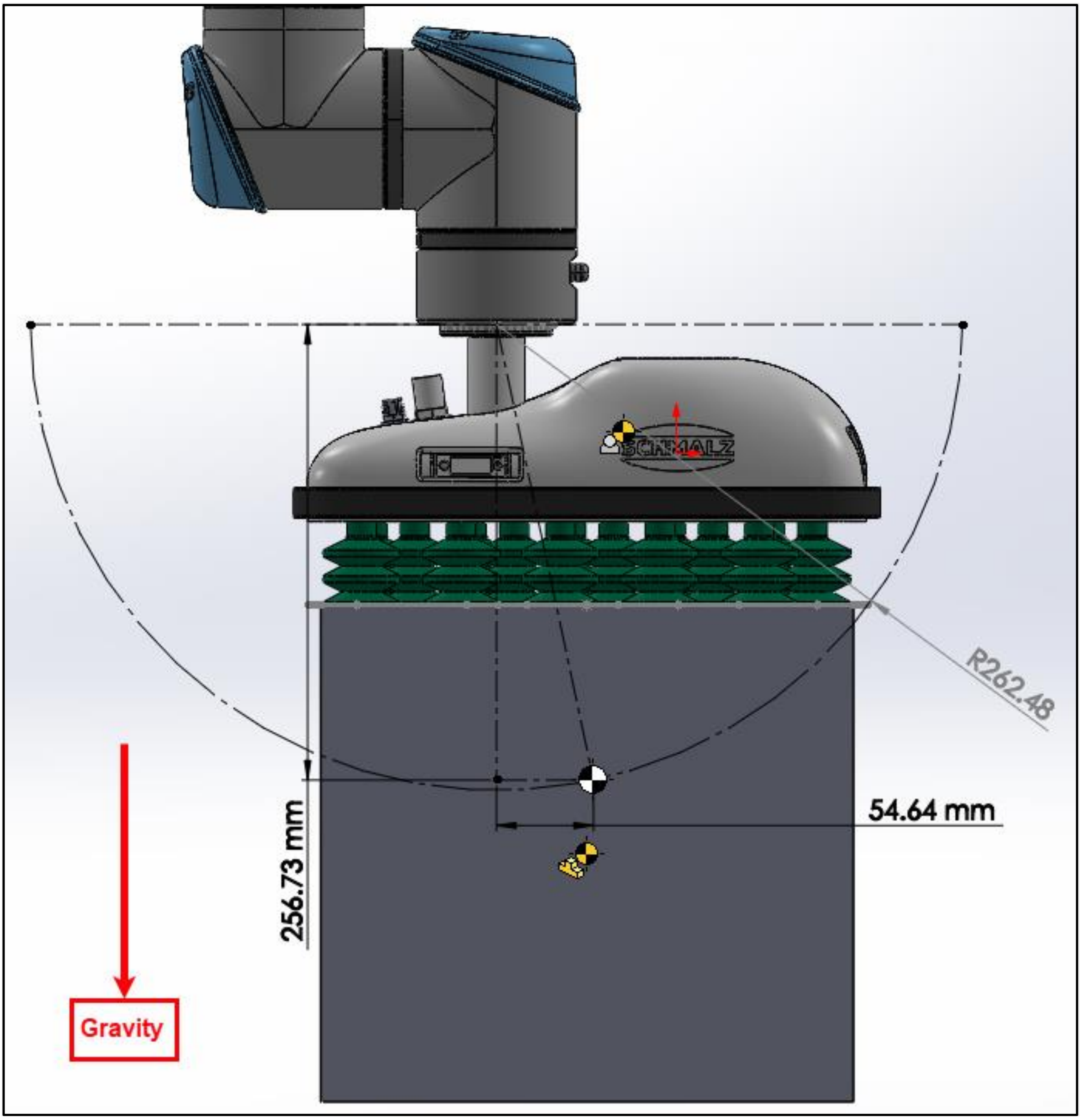


FIGURE 12 – COG LOCATION SKETCHED ONTO MODEL

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 13**, 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 is outside of the shaded region.

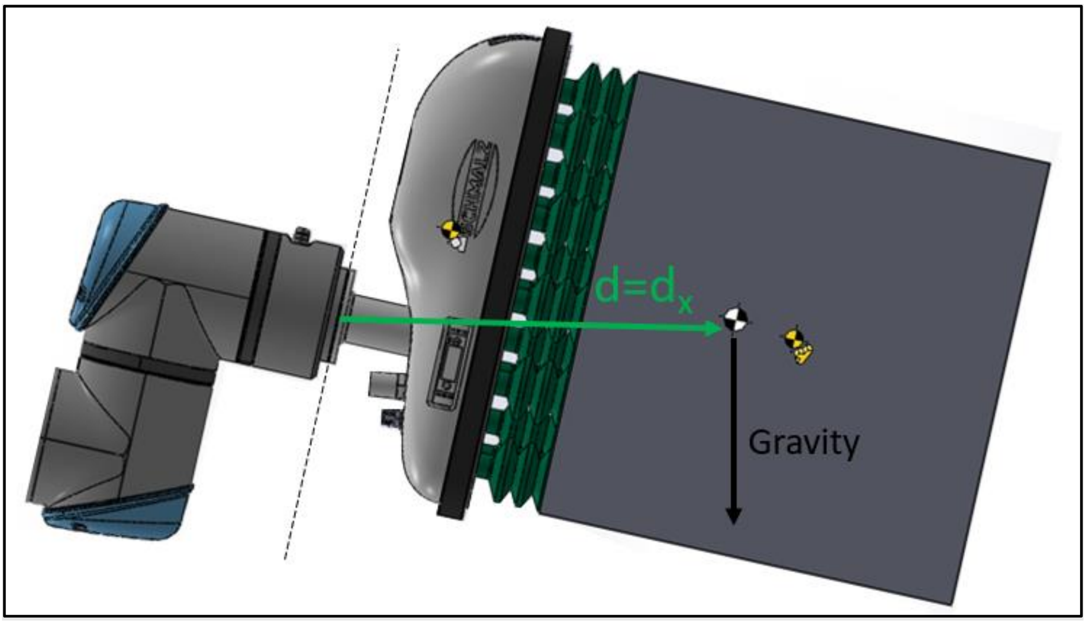


FIGURE 13 – COG LOCATION SKETCHED ONTO MODEL

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 restricts external control software or users from tilting the tool flange. As a result, the system protects itself from inadvertent stops/faults during runtime. 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 +/- **15 degrees**, as shown in **FIGURE 14**.

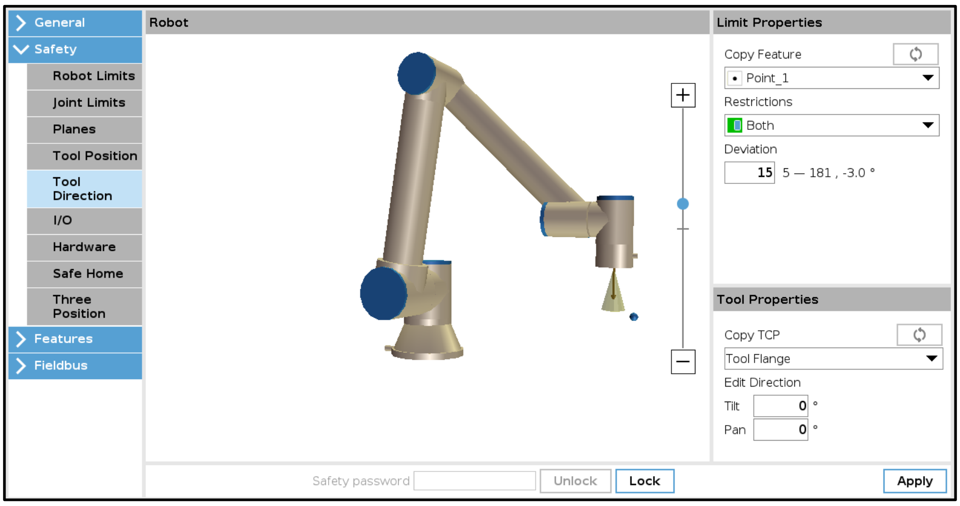


FIGURE 14 – TOOL DIRECTION CONFIGURATION

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 in **Section 3**, the tool flange will remain in the orientation shown in FIGURE 12 based on the conclusion outlined in **Section 3.1.2**. As a result, 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, see FIGURE 15.

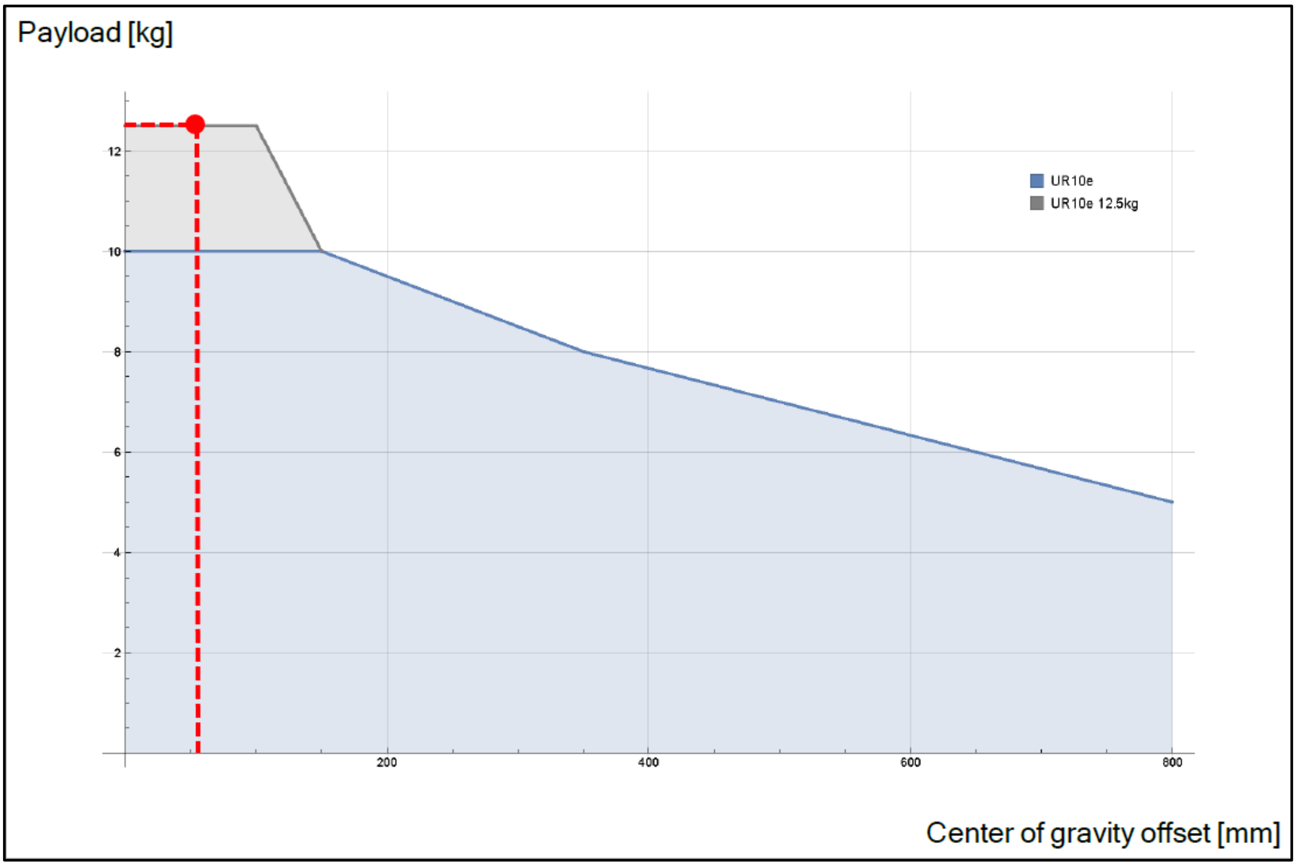


FIGURE 15 – MAXIMUM PAYLOAD FOR HORIZONTAL COMPONENT OF COMBINED PAYLOAD

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.

<table>
<tr><th>Palletizing UR10e</th><th>Benchmark case</th></tr>
<tr><td>Total Payload</td><td>12.5 kg</td></tr>
<tr><td>Tool Load</td><td>2.17 kg
CoG location (from Tool Flange)
X = 0mm Y = -71.95mm Z = 60.16mm
MOI
<table>
<tr><td>I</td><td>X</td><td>Y</td><td>Z</td></tr>
<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>
</table></td></tr>
<tr><td>Combined Load (Tool and Part)</td><td>12.5 kg
CoG location
X = 0mm Y = -54.64mm Z = 256.73mm
Horizontal CoG component: 54.64mm
MOI
<table>
<tr><td>I</td><td>X</td><td>Y</td><td>Z</td></tr>
<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>
</table></td></tr>
<tr><td>Capacity</td><td>7.9 cases/ minute
~7.594 seconds/ cycle</td></tr>
</table>

TABLE 3 – PALLETIZING EXAMPLE SIMULATION RESULTS

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