

Inertia Tensors, Masses, and CGs for the BarrettHand BH8-262

(version 02, 2008-Mar-04)

Dear Reader,

The initial draft of this document was prepared for Yuandong Yang yuandong@robotics-mail.cs.umass.edu in late August, 2007. Yuandong may have information on how he used the data and the results of its use. If you find any errors in this document, please feed them back to me, its author, Bill Townsend wt@barrett.com

The data was not updated between Versions 01 and 02. The only changes were a rewrite of this cover sheet and deleting a blank last page.

The data given was calculated from Barrett's SolidWorks CAD model using SolidWorks2006, version 5.1. (The reader may find it interesting that the original BarrettHand was the first machine ever designed in SolidWorks CAD. Indeed the first manuals shipped with the initial launch of SolidWorks contained almost exclusively BarrettHand part, assembly, and drawing examples.)

While this document is rough around the edges, the graphics are clear, and I believe that the data matches the model within 1 percent. I exploited transparency properties as much as possible to make clear which parts are associated with which link. Since no one is likely to wish to attempt computed-torque control on the Hand axes (since the frictions in the Hand are very high), I did not compute the backdriven, reflected drive inertias of the drives. Since backdriven drive inertias have no effect on gravity terms, the frame inertias should give you good results for controlling the WAM arm and wrist torques as functions of hand-finger positions.

The base of the Hand is modeled without the separable ring nut, which is not used to connect the BarrettHand to the WAM arm.

When summed, the data from this document gives the strain-gaged Hand mass at
 $1.235 \text{ kg} \quad (\text{B3470} + 2 * \text{B3471} + 3 * (\text{B3472} + \text{B3476}))$
and the non-strain-gaged Hand mass at
 $1.223 \text{ kg} \quad (\text{B3470} + 2 * \text{B3471} + 3 * (\text{B3473} + \text{B3476})).$

These numbers are slightly higher than the true weights of the Hand. We measured a Hand (ser#HND-132) without strain-gage beams installed, but with their connectors installed on 2008-Mar-04 which weighed in at 1.220 kg. The nominal spec for a Hand is 1.180 kg, and we are not sure of the source of the 40-gm difference.

To repeat, please let me know as you find (or even suspect) other errors in the data presented here.

Good luck,

Bill T. wt@barrett.com

SW Mass Properties

Print... Copy Close Options... Recalculate

Output Coordinate System: -- default --

Selected Items: B3470.SLDASM

Include Hidden Bodies/Components
 Show output coordinate system in corner of window
 Assigned Mass Properties

Mass properties of B3470 (Assembly Configuration - WithStrainGageOption)

Output coordinate System: -- default --

Density = 3205.70736898 kilograms per cubic meter

Mass = 0.63352875 kilograms

Volume = 0.00019763 cubic meters

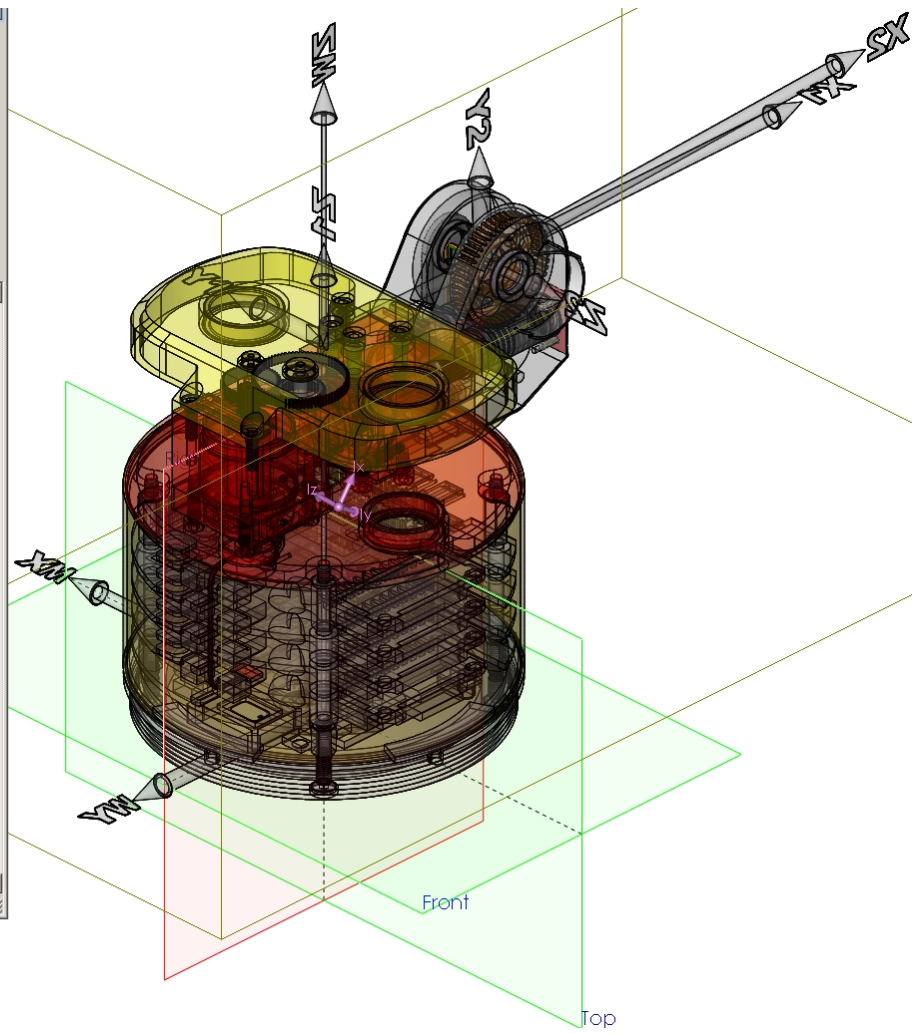
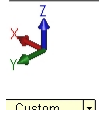
Surface area = 0.23982378 meters^2

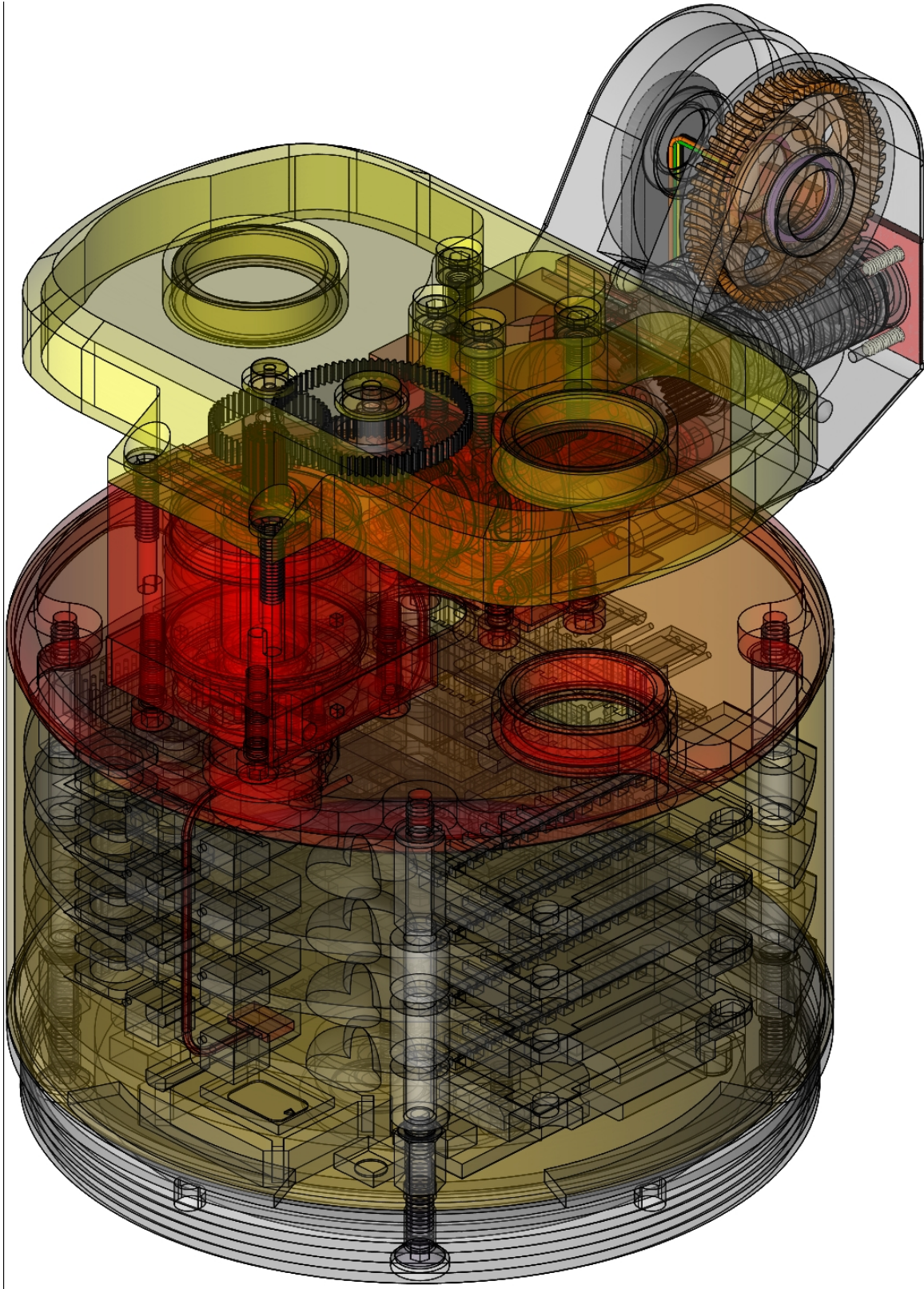
Center of mass: (meters)
 X = 0.00035500
 Y = -0.00499005
 Z = 0.04864979

Principal axes of inertia and principal moments of inertia: (kilograms * square meters)
 Taken at the center of mass.
 Ix = (-0.03383328, -0.55260676, 0.83275511) Px = 0.00059171
 Iy = (0.00298160, -0.83328425, -0.55283675) Py = 0.00090512
 Iz = (0.99942304, -0.01622134, 0.02984039) Pz = 0.00102153

Moments of inertia: (kilograms * square meters)
 Taken at the center of mass and aligned with the output coordinate system.
 Lxx = 0.00102103 Lxy = 0.00000775 Lxz = -0.00001230
 Lyx = 0.00000775 Lyy = 0.00080944 Lyz = -0.00014417
 Lzx = -0.00001230 Lzy = -0.00014417 Lzz = 0.00068788

Moments of inertia: (kilograms * square meters)
 Taken at the output coordinate system.
 Ixx = 0.00253625 Ixy = 0.00000662 Ixz = -0.00000136
 Iyx = 0.00000662 Iyy = 0.00230896 Iyz = -0.00029797
 Izx = -0.00000136 Izy = -0.00029797 Izz = 0.00070373





Mass properties of B3470 (Assembly Configuration - WithStrainGageOption)

Density = 3205.70736898 kilograms per cubic meter

Mass = 0.63352875 kilograms

Volume = 0.00019763 cubic meters

Surface area = 0.23982378 meters²

Center of mass: (meters)

X = 0.00035500

Y = -0.00499005

Z = 0.04864979

Principal axes of inertia and principal moments of inertia: (kilograms * square meters)

Taken at the center of mass.

I_x = (-0.03383328, -0.55260676, 0.83275511) P_x = 0.00059171

I_y = (0.00298160, -0.83328425, -0.55283675) P_y = 0.00090512

I_z = (0.99942304, -0.01622134, 0.02984039) P_z = 0.00102153

Moments of inertia: (kilograms * square meters)

Taken at the center of mass and aligned with the output coordinate system.

L_{xx} = 0.00102103 L_{xy} = 0.00000775 L_{xz} = -0.00001230

L_{yx} = 0.00000775 L_{yy} = 0.00080944 L_{yz} = -0.00014417

L_{zx} = -0.00001230 L_{zy} = -0.00014417 L_{zz} = 0.00068788

Moments of inertia: (kilograms * square meters)

Taken at the output coordinate system.

I_{xx} = 0.00253625 I_{xy} = 0.00000662 I_{xz} = -0.00000136

I_{yx} = 0.00000662 I_{yy} = 0.00230896 I_{yz} = -0.00029797

I_{zx} = -0.00000136 I_{zy} = -0.00029797 I_{zz} = 0.00070373

Selected Items: B3471.SLDASM

Include Hidden Bodies/Components
 Show output coordinate system in corner of window
 Assigned Mass Properties

Mass properties of B3471 (Assembly Configuration - WithStrainGageOption)

Output coordinate System: -- default --

Density = 3738.20010426 kilograms per cubic meter

Mass = 0.16252678 kilograms

Volume = 0.00004348 cubic meters

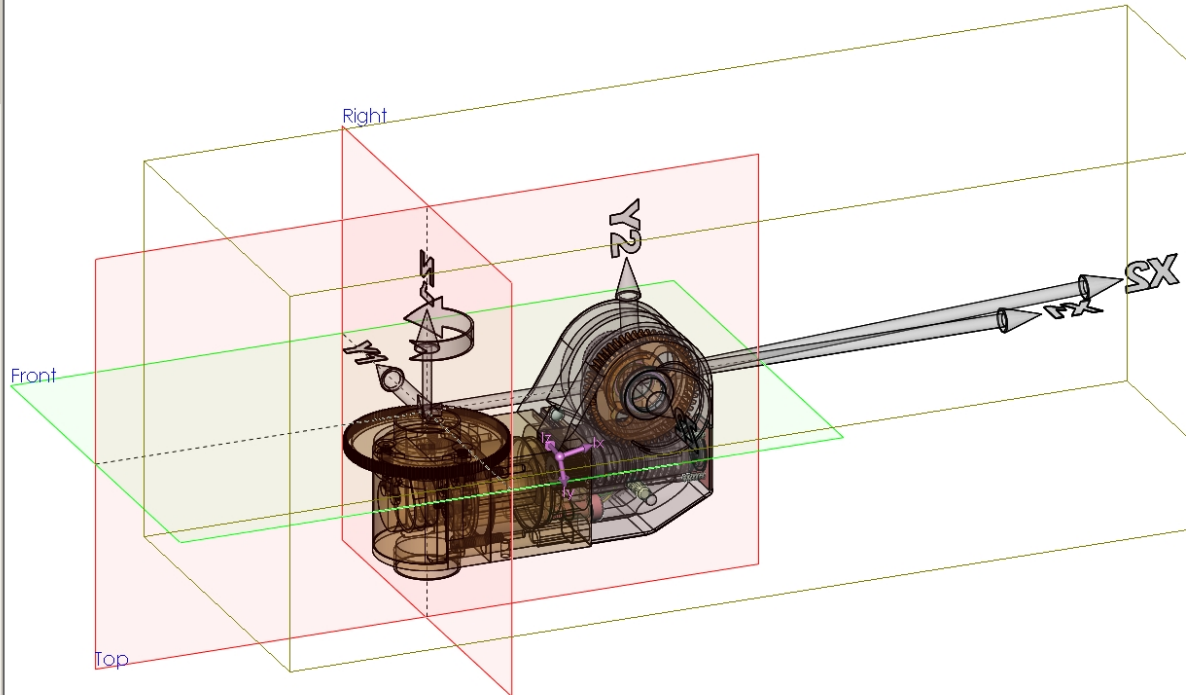
Surface area = 0.05418535 meters^2

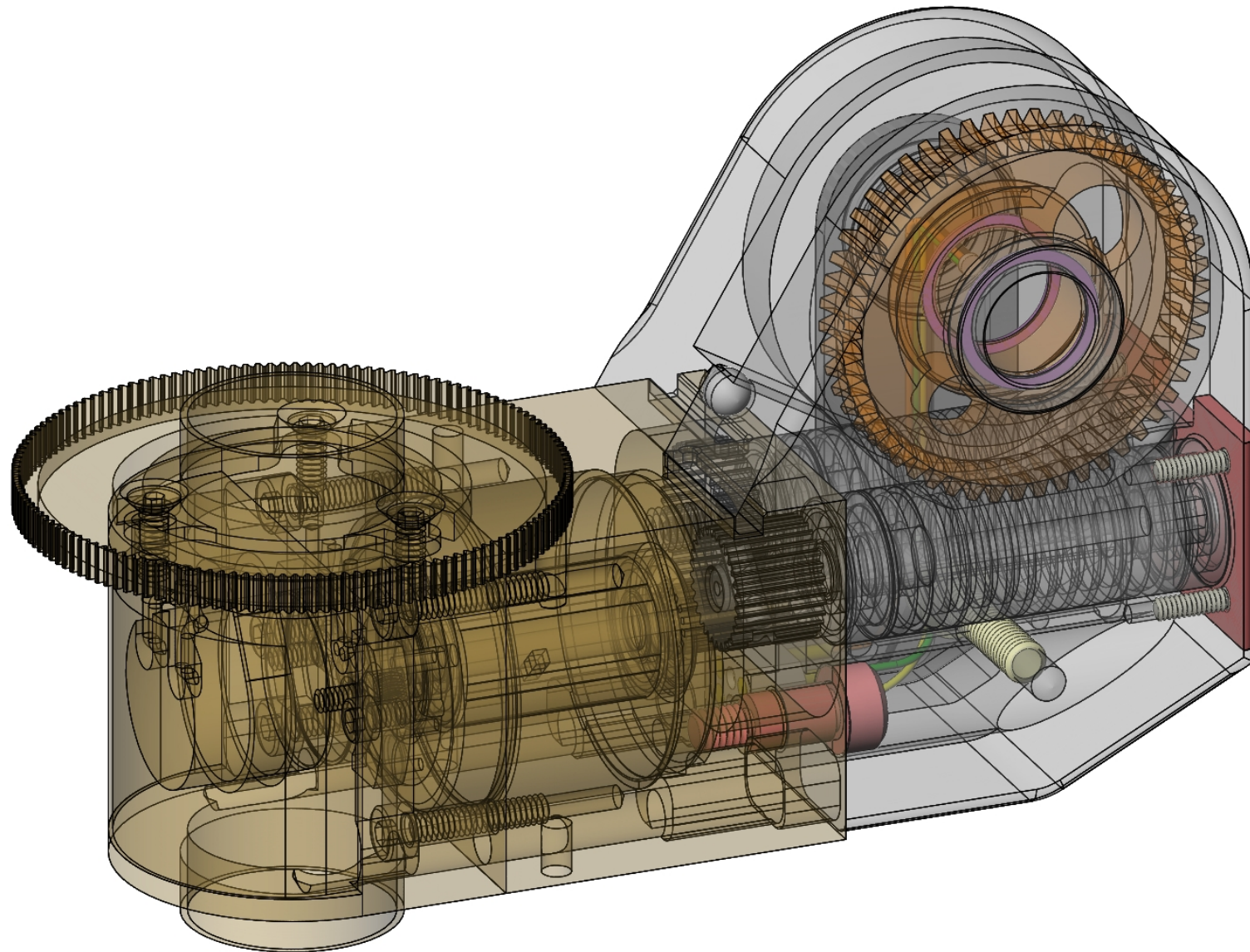
Center of mass: (meters)
 X = 0.03201666
 Y = -0.00086502
 Z = -0.01569925

Principal axes of inertia and principal moments of inertia: (kilograms * square meters)
 Taken at the center of mass.
 Ix = (0.97919668, -0.02501033, 0.20136621) Px = 0.00002332
 Iy = (0.20275694, 0.08163084, -0.97582069) Py = 0.00008053
 Iz = (0.00796790, 0.99634878, 0.08500366) Pz = 0.00008827

Moments of inertia: (kilograms * square meters)
 Taken at the center of mass and aligned with the output coordinate system.
 Lxx = 0.00002567 Lxy = -0.00000146 Lxz = 0.00001128
 Lyx = -0.00000146 Lyy = 0.00008818 Lyz = -0.00000094
 Lzx = 0.00001128 Lzy = -0.00000094 Lzz = 0.00007827

Moments of inertia: (kilograms * square meters)
 Taken at the output coordinate system.
 Ixx = 0.00006585 Ixy = -0.00000596 Ixz = -0.00007042
 Iyx = -0.00000596 Iyy = 0.00029484 Iyz = 0.00000126
 Izx = -0.00007042 Izy = 0.00000126 Izz = 0.00024499





Mass properties of B3471 (Assembly Configuration - WithStrainGageOption)

Density = 3738.20010426 kilograms per cubic meter

Mass = 0.16252678 kilograms

Volume = 0.00004348 cubic meters

Surface area = 0.05418535 meters²

Center of mass: (meters)

X = 0.03201666

Y = -0.00086502

Z = -0.01569925

Principal axes of inertia and principal moments of inertia: (kilograms * square meters)

Taken at the center of mass.

Ix = (0.97919668, -0.02501033, 0.20136621) Px = 0.00002332

Iy = (0.20275694, 0.08163084, -0.97582069) Py = 0.00008053

Iz = (0.00796790, 0.99634878, 0.08500366) Pz = 0.00008827

Moments of inertia: (kilograms * square meters)

Taken at the center of mass and aligned with the output coordinate system.

Lxx = 0.00002567 Lxy = -0.00000146 Lxz = 0.00001128

Lyx = -0.00000146 Lyy = 0.00008818 Lyz = -0.00000094

Lzx = 0.00001128 Lzy = -0.00000094 Lzz = 0.00007827

Moments of inertia: (kilograms * square meters)

Taken at the output coordinate system.

Ixx = 0.00006585 Ixy = -0.00000596 Ixz = -0.00007042

Iyx = -0.00000596 Iyy = 0.00029484 Iyz = 0.00000126

Izx = -0.00007042 Izy = 0.00000126 Izz = 0.00024499

Mass Properties

Print... Copy Close Options... Recalculate

Output Coordinate System: -- default --

Selected Items: B3472.SLDASM

Include Hidden Bodies/Components

Show output coordinate system in corner of window

Assigned Mass Properties

Mass properties of B3472 (Assembly Configuration - Default)

Output coordinate System: -- default --

Density = 0.003 grams per cubic millimeter

Mass = 57.957 grams

Volume = 19754.166 cubic millimeters

Surface area = 26796.433 millimeters^2

Center of mass: (millimeters)

X = 31.720
Y = 1.070
Z = -0.586

Principal axes of inertia and principal moments of inertia: (grams * square millimeters)

Taken at the center of mass.

Ix = (0.999, 0.011, 0.051)	Px = 4526.198
Iy = (-0.012, 1.000, 0.028)	Py = 35904.971
Iz = (-0.051, -0.029, 0.998)	Pz = 36913.699

Moments of inertia: (grams * square millimeters)

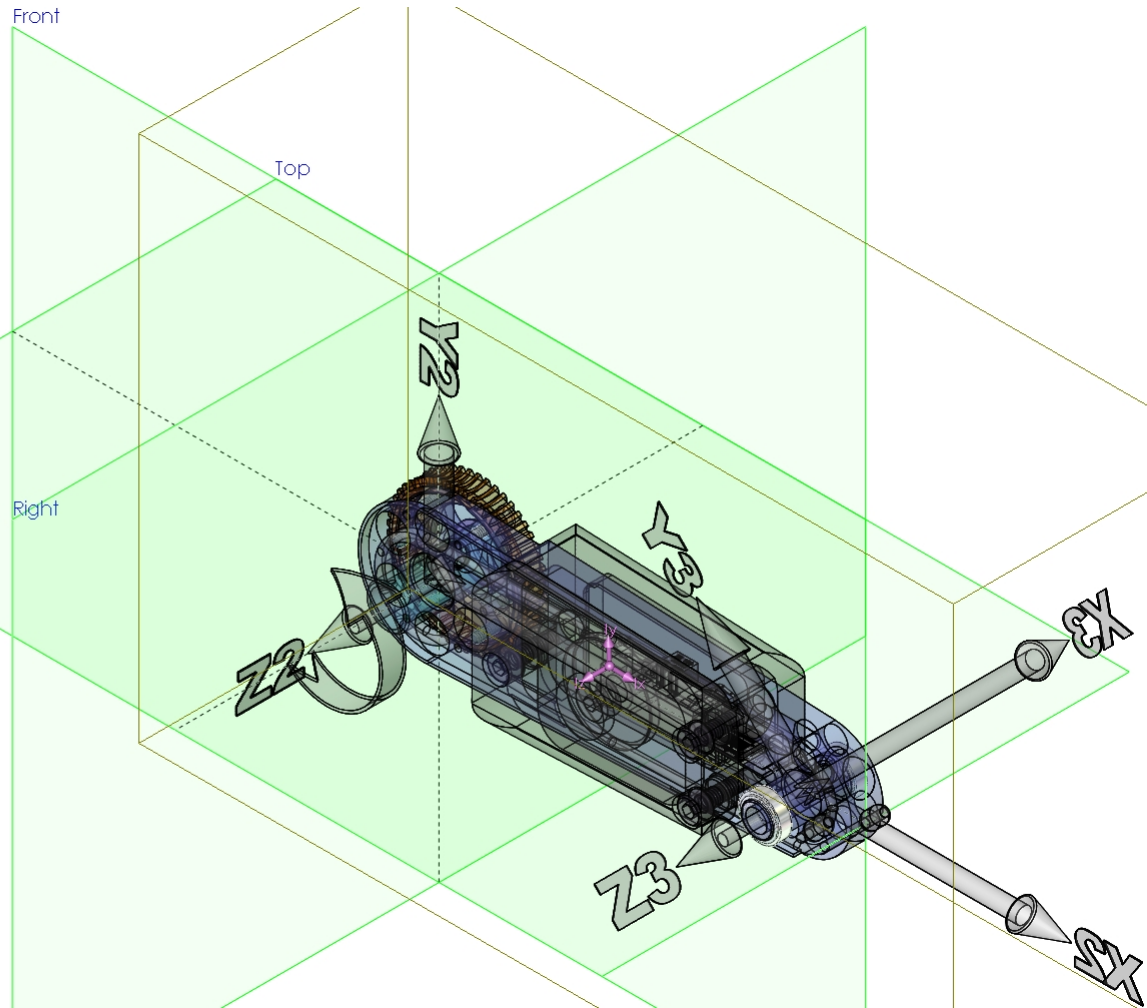
Taken at the center of mass and aligned with the output coordinate system.

Lxx = 4614.085	Lxy = 337.086	Lxz = 1649.347
Lyx = 337.086	Lyx = 35902.138	Lyz = 46.158
Lzx = 1649.347	Lzy = 46.158	Lzz = 36828.645

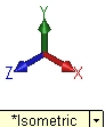
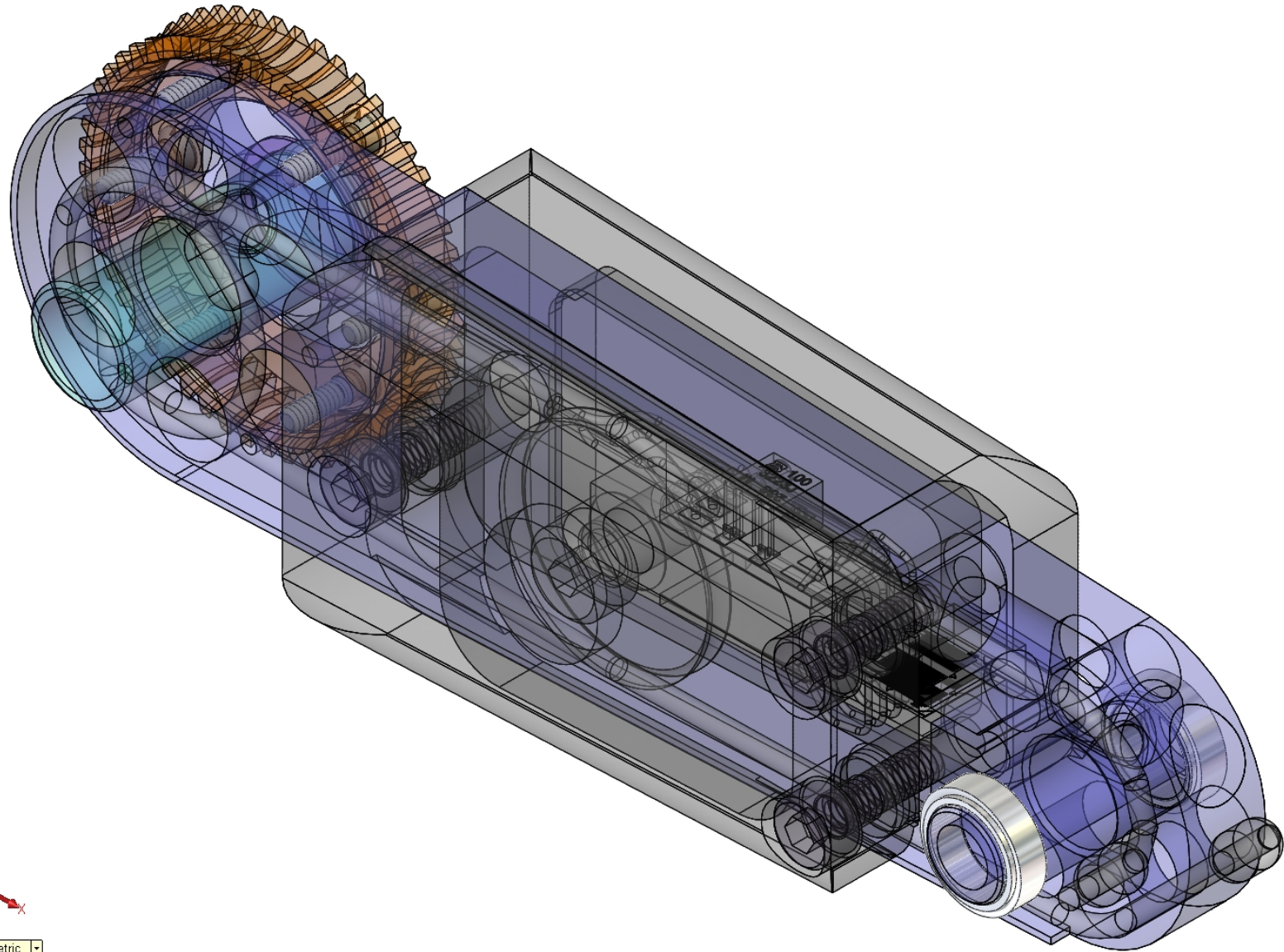
Moments of inertia: (grams * square millimeters)

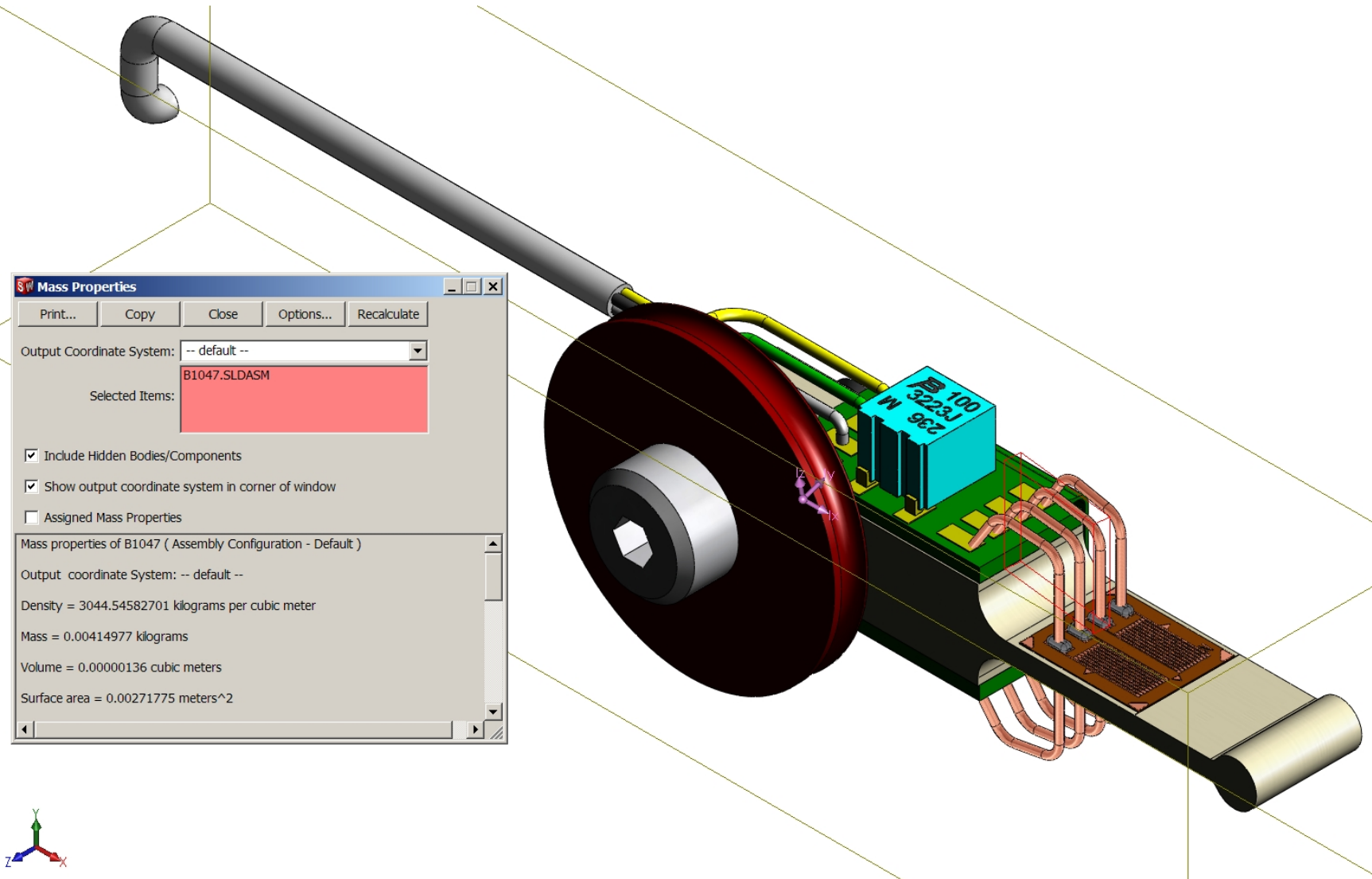
Taken at the output coordinate system.

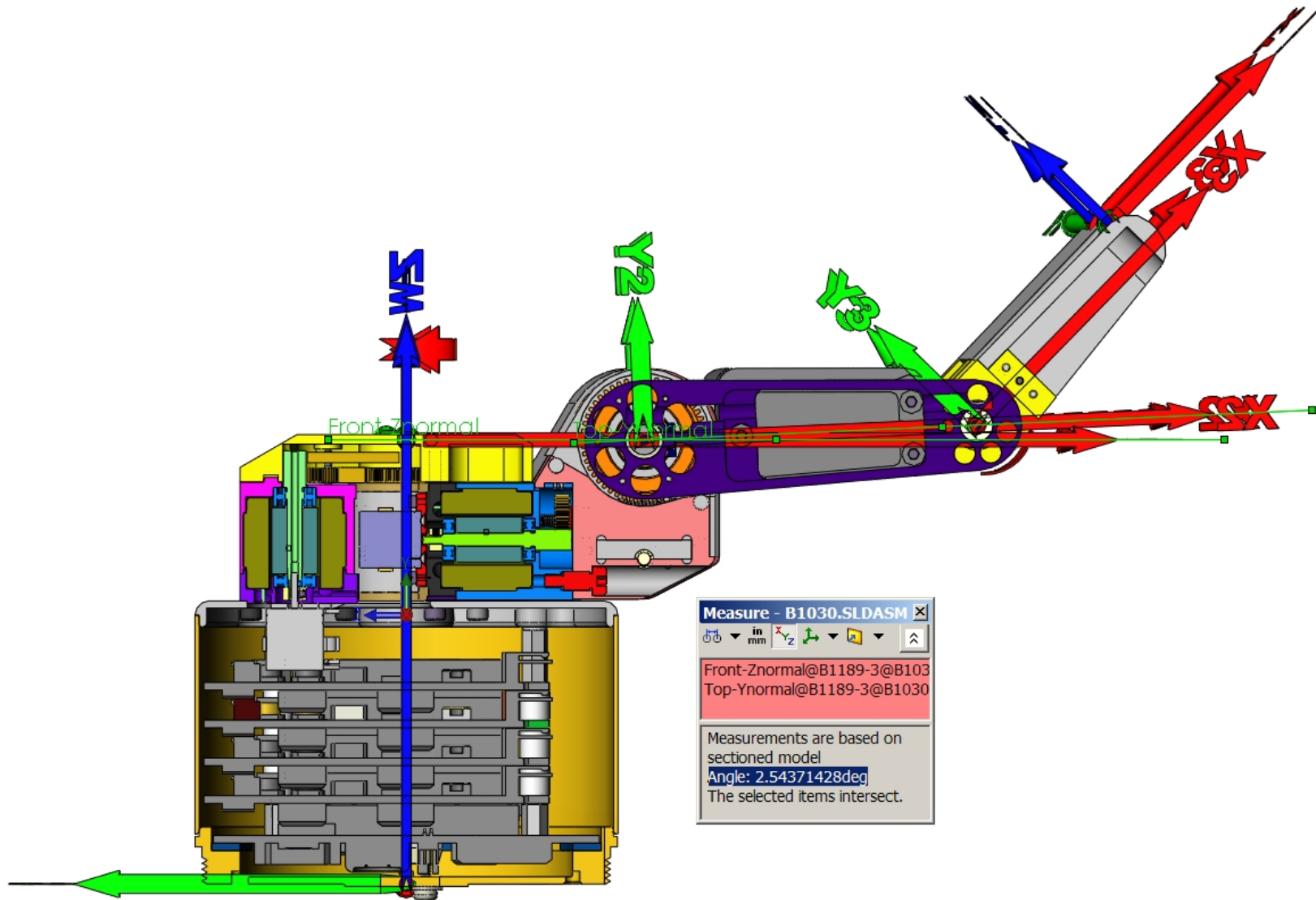
Ixx = 4700.415	Ixy = 2304.981	Ixz = 571.511
Iyx = 2304.981	Iyy = 94237.082	Iyz = 9.785
Izx = 571.511	Izy = 9.785	Izz = 95210.076



*Isometric







Mass properties of B3472 (Assembly Configuration - Default)

Density = 3085.63509216 kilograms per cubic meter

Mass = 0.05795741 kilograms

Volume = 0.00001878 cubic meters

Surface area = 0.02509034 meters²

Center of mass: (meters)

X = 0.03172018

Y = 0.00107042

Z = -0.00058628

Principal axes of inertia and principal moments of inertia: (kilograms * square meters)

Taken at the center of mass.

I_x = (0.99863993, 0.01080386, 0.05100547) P_x = 0.00000453I_y = (-0.01224756, 0.99953071, 0.02807762) P_y = 0.00003590I_z = (-0.05067819, -0.02866412, 0.99830361) P_z = 0.00003691

Moments of inertia: (kilograms * square meters)

Taken at the center of mass and aligned with the output coordinate system.

L_{xx} = 0.00000461 L_{xy} = 0.00000034 L_{xz} = 0.00000165L_{yx} = 0.00000034 L_{yy} = 0.00003590 L_{yz} = 0.00000005L_{zx} = 0.00000165 L_{zy} = 0.00000005 L_{zz} = 0.00003683

Moments of inertia: (kilograms * square meters)

Taken at the output coordinate system.

I_{xx} = 0.00000470 I_{xy} = 0.00000230 I_{xz} = 0.00000057I_{yx} = 0.00000230 I_{yy} = 0.00009424 I_{yz} = 0.00000000I_{zx} = 0.00000057 I_{zy} = 0.00000000 I_{zz} = 0.00009521

Mass Properties

Print... Copy Close Options... Recalculate

Output Coordinate System: -- default --

Selected Items: B3473.SLDASM

Include Hidden Bodies/Components

Show output coordinate system in corner of window

Assigned Mass Properties

Mass properties of B3473 (Assembly Configuration - Default)

Output coordinate System: -- default --

Density = 2925.73632911 kilograms per cubic meter

Mass = 0.05380765 kilograms

Volume = 0.00001839 cubic meters

Surface area = 0.02407868 meters^2

Center of mass: (meters)

X = 0.03122559
 Y = 0.00112180
 Z = -0.00062961

Principal axes of inertia and principal moments of inertia: (kilograms * square meters)

Taken at the center of mass.

Ix = (0.99854419, 0.01259932, 0.05244770)	Px = 0.00000446
Iy = (-0.01405156, 0.99952542, 0.02741326)	Py = 0.00003523
Iz = (-0.05207742, -0.02811033, 0.99824734)	Pz = 0.00003625

Moments of inertia: (kilograms * square meters)

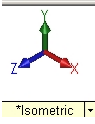
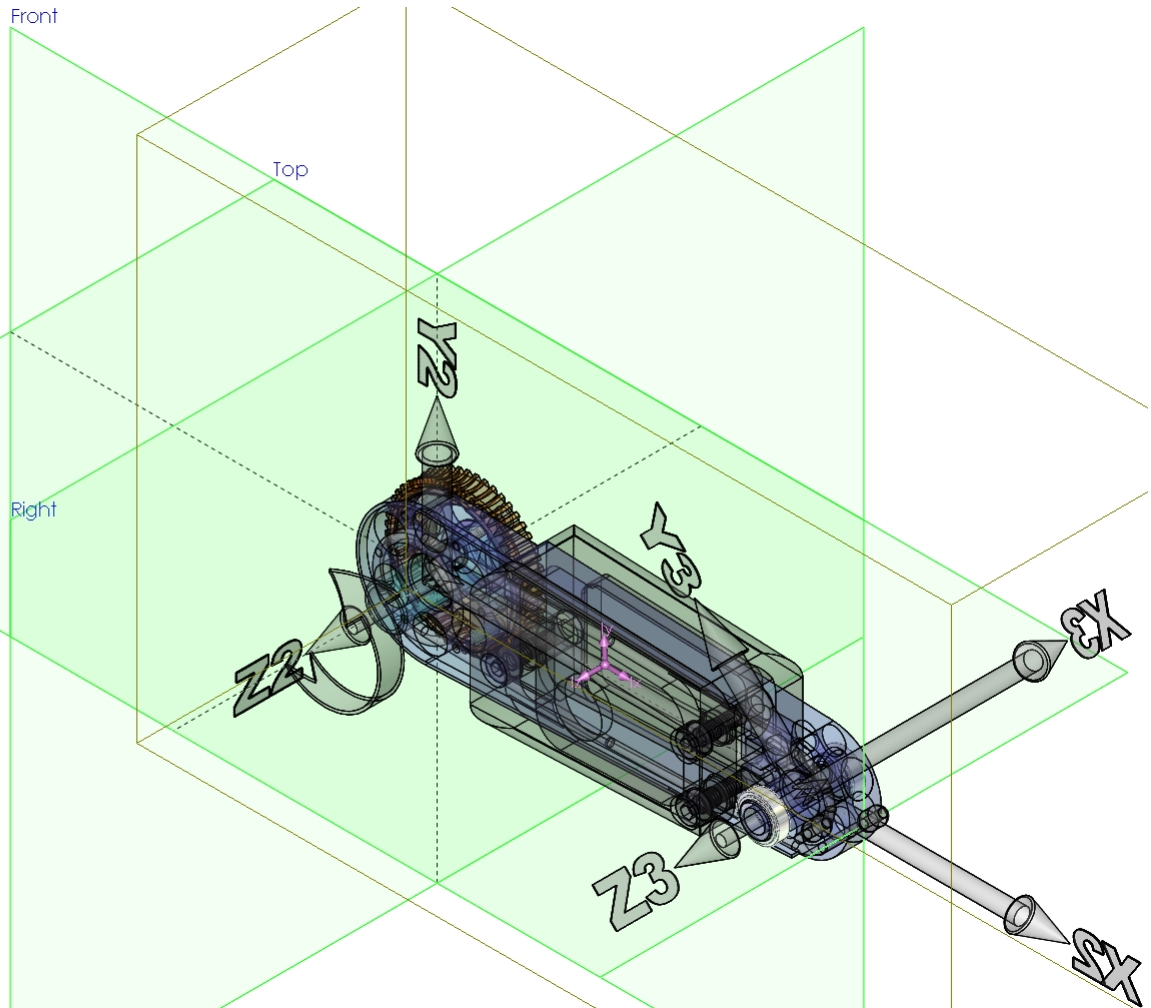
Taken at the center of mass and aligned with the output coordinate system.

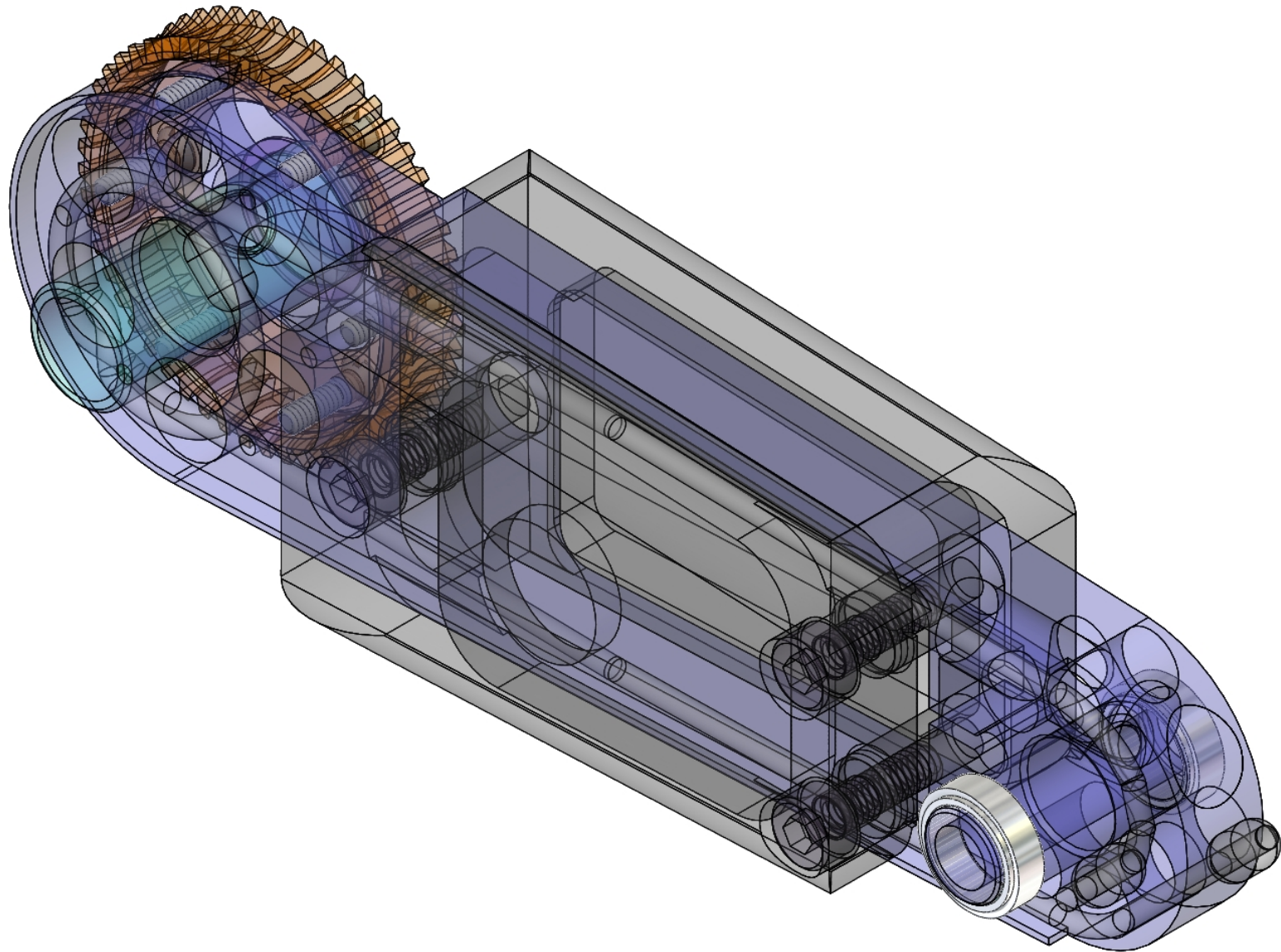
Lxx = 0.00000455	Lxy = 0.00000039	Lxz = 0.00000166
Lyx = 0.00000039	Lyx = 0.00003522	Lyz = 0.00000005
Lzx = 0.00000166	Lzy = 0.00000005	Lzz = 0.00003616

Moments of inertia: (kilograms * square meters)

Taken at the output coordinate system.

Ixx = 0.00000464	Ixy = 0.00000227	Ixz = 0.00000061
Iyx = 0.00000227	Iyy = 0.00008771	Iyz = 0.00000001
Izx = 0.00000061	Izy = 0.00000001	Izz = 0.00008869





Mass properties of B3473 (Assembly Configuration - Default)

Density = 3088.85010288 kilograms per cubic meter

Mass = 0.05380764 kilograms

Volume = 0.00001742 cubic meters

Surface area = 0.02237259 meters²

Center of mass: (meters)

X = 0.03122559

Y = 0.00112179

Z = -0.00062961

Principal axes of inertia and principal moments of inertia: (kilograms * square meters)

Taken at the center of mass.

I_x = (0.99854419, 0.01259930, 0.05244767) P_x = 0.00000446

I_y = (-0.01405150, 0.99952544, 0.02741244) P_y = 0.00003523

I_z = (-0.05207740, -0.02810950, 0.99824736) P_z = 0.00003625

Moments of inertia: (kilograms * square meters)

Taken at the center of mass and aligned with the output coordinate system.

L_{xx} = 0.00000455 L_{xy} = 0.00000039 L_{xz} = 0.00000166

L_{yx} = 0.00000039 L_{yy} = 0.00003522 L_{yz} = 0.00000005

L_{zx} = 0.00000166 L_{zy} = 0.00000005 L_{zz} = 0.00003616

Moments of inertia: (kilograms * square meters)

Taken at the output coordinate system.

I_{xx} = 0.00000464 I_{xy} = 0.00000227 I_{xz} = 0.00000061

I_{yx} = 0.00000227 I_{yy} = 0.00008771 I_{yz} = 0.00000001

I_{zx} = 0.00000061 I_{zy} = 0.00000001 I_{zz} = 0.00008869

Include Hidden Bodies/Components
 Show output coordinate system in corner of window
 Assigned Mass Properties

Mass properties of 5 (Assembly Configuration - Default)

Output coordinate System: -- default --

Density = 2245.68077726 kilograms per cubic meter

Mass = 0.01610049 kilograms

Volume = 0.00000717 cubic meters

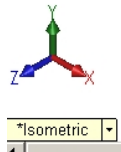
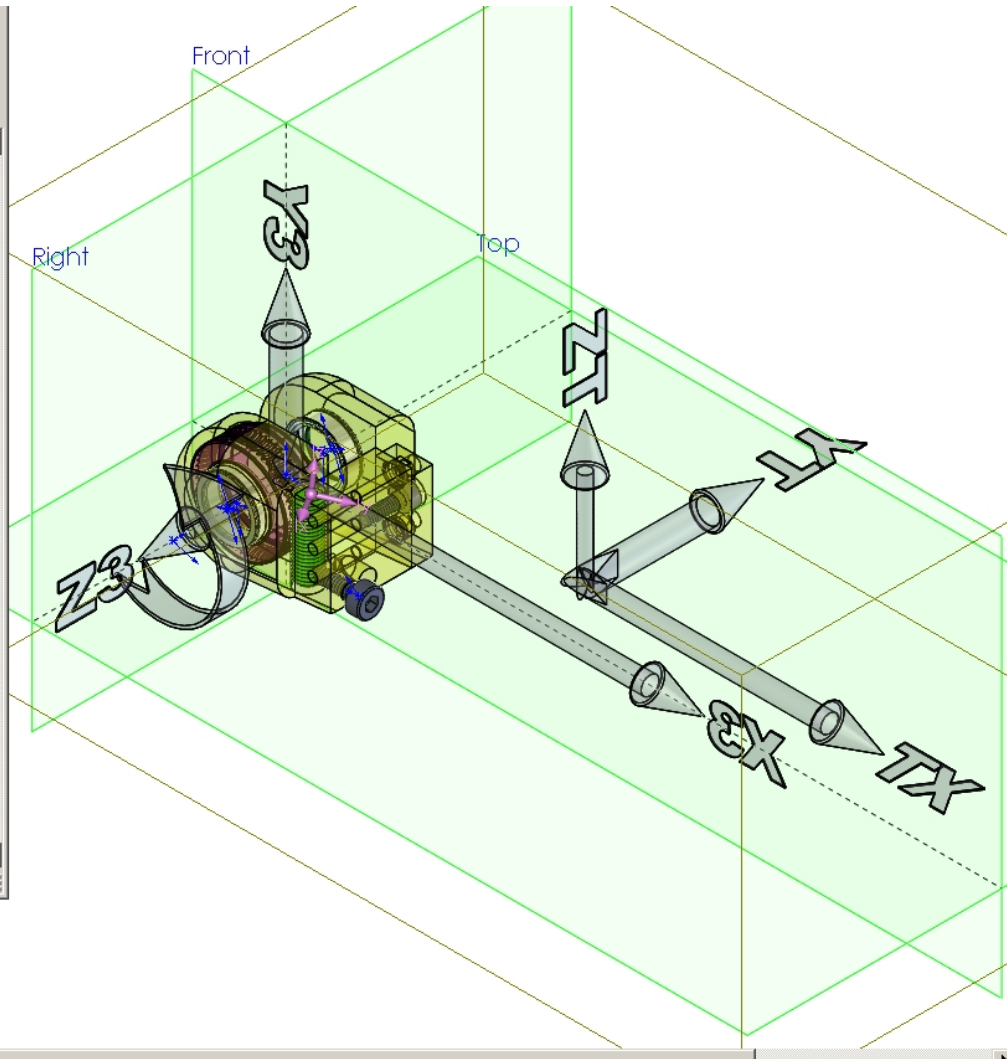
Surface area = 0.00949114 meters^2

Center of mass: (meters)
 X = 0.00459747
 Y = -0.00019176
 Z = 0.00041465

Principal axes of inertia and principal moments of inertia: (kilograms * square meters)
 Taken at the center of mass.
 Ix = (0.50695587, -0.06237633, 0.85971212) Px = 0.00000115
 Iy = (0.85340706, -0.10393084, -0.51077859) Py = 0.00000122
 Iz = (0.12121110, 0.99262660, 0.00054405) Pz = 0.00000163

Moments of inertia: (kilograms * square meters)
 Taken at the center of mass and aligned with the output coordinate system.
 Lxx = 0.00000121 Lxy = -0.00000005 Lxz = 0.00000003
 Lyx = -0.00000005 Lyy = 0.00000163 Lyz = 0.00000000
 Lzx = 0.00000003 Lzy = 0.00000000 Lzz = 0.00000117

Moments of inertia: (kilograms * square meters)
 Taken at the output coordinate system.
 Ixx = 0.00000122 Ixy = -0.00000007 Ixz = 0.00000006
 Iyx = -0.00000007 Iyy = 0.00000197 Iyz = 0.00000000
 Izx = 0.00000006 Izy = 0.00000000 Izz = 0.00000151



Mass properties of B3474 (Assembly Configuration - Default)

Density = 2245.68077726 kilograms per cubic meter

Mass = 0.01610049 kilograms

Volume = 0.00000717 cubic meters

Surface area = 0.00949114 meters²

Center of mass: (meters)

X = 0.00459747

Y = -0.00019176

Z = 0.00041465

Principal axes of inertia and principal moments of inertia: (kilograms * square meters)

Taken at the center of mass.

Ix = (0.50695587, -0.06237633, 0.85971212) Px = 0.00000115

Iy = (0.85340706, -0.10393084, -0.51077859) Py = 0.00000122

Iz = (0.12121110, 0.99262660, 0.00054405) Pz = 0.00000163

Moments of inertia: (kilograms * square meters)

Taken at the center of mass and aligned with the output coordinate system.

Lxx = 0.00000121 Lxy = -0.00000005 Lxz = 0.00000003

Lyx = -0.00000005 Lyy = 0.00000163 Lyz = 0.00000000

Lzx = 0.00000003 Lzy = 0.00000000 Lzz = 0.00000117

Moments of inertia: (kilograms * square meters)

Taken at the output coordinate system.

Ixx = 0.00000122 Ixy = -0.00000007 Ixz = 0.00000006

Iyx = -0.00000007 Iyy = 0.00000197 Iyz = 0.00000000

Izx = 0.00000006 Izy = 0.00000000 Izz = 0.00000151

Include Hidden Bodies/Components
 Show output coordinate system in corner of window
 Assigned Mass Properties

Mass properties of 6 (Assembly Configuration - Default)

Output coordinate System: -- default --

Density = 2378.27997141 kilograms per cubic meter

Mass = 0.01811732 kilograms

Volume = 0.00000762 cubic meters

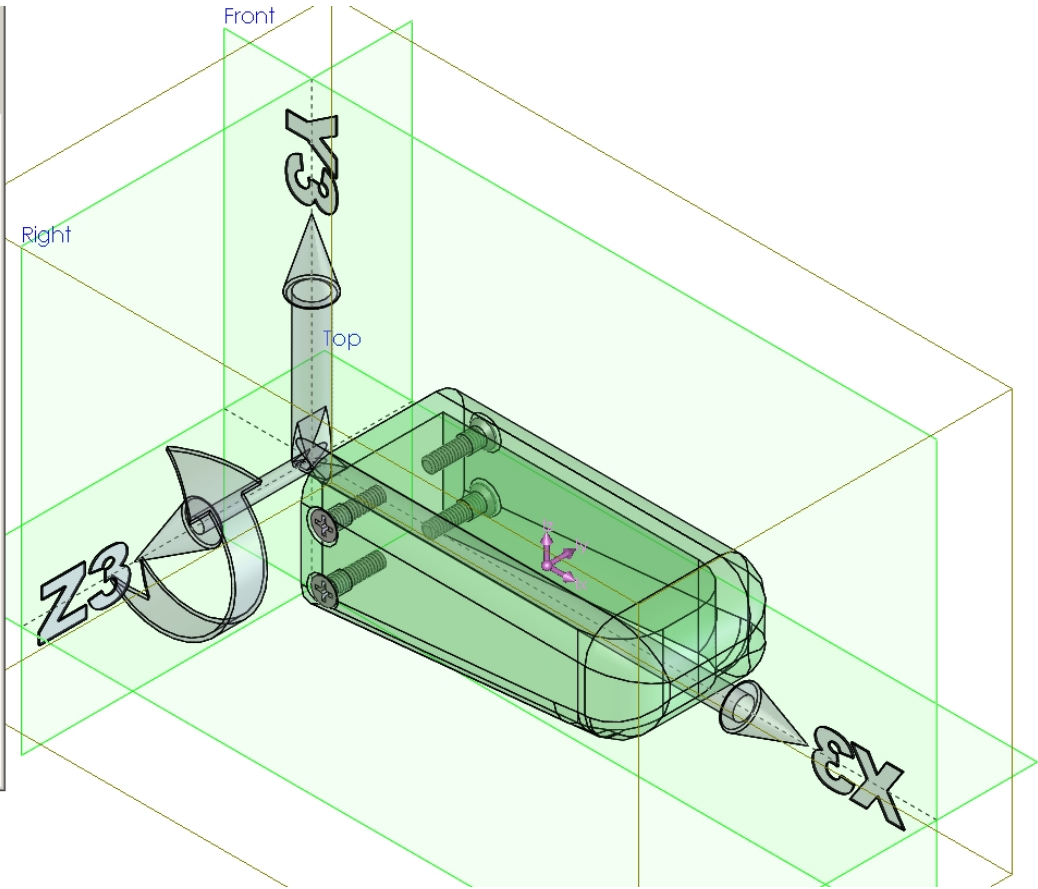
Surface area = 0.00730548 meters^2

Center of mass: (meters)
X = 0.03313970
Y = 0.00360812
Z = 0.00000000

Principal axes of inertia and principal moments of inertia: (kilograms * square meters)
Taken at the center of mass.
Ix = (0.99992500, 0.01224728, 0.00000000) Px = 0.00000154
Iy = (0.00000000, 0.00000128, -1.00000000) Py = 0.00000390
Iz = (-0.01224728, 0.99992500, 0.00000129) Pz = 0.00000471

Moments of inertia: (kilograms * square meters)
Taken at the center of mass and aligned with the output coordinate system.
Lxx = 0.00000154 Lxy = 0.00000004 Lxz = 0.00000000
Lyx = 0.00000004 Lyz = 0.00000471 Lzy = 0.00000000
Lzx = 0.00000000 Lzy = 0.00000000 Lzz = 0.00000390

Moments of inertia: (kilograms * square meters)
Taken at the output coordinate system.
Ixx = 0.00000177 Ixy = 0.00000221 Ixz = 0.00000000
Iyx = 0.00000221 Iyy = 0.00002461 Iyz = 0.00000000
Izx = 0.00000000 Izy = 0.00000000 Izx = 0.00002403



Mass properties of B3475 (Assembly Configuration - Default)

Density = 2378.27997141 kilograms per cubic meter

Mass = 0.01811732 kilograms

Volume = 0.00000762 cubic meters

Surface area = 0.00730548 meters²

Center of mass: (meters)

X = 0.03313970

Y = 0.00360812

Z = 0.00000000

Principal axes of inertia and principal moments of inertia: (kilograms * square meters)

Taken at the center of mass.

I_x = (0.99992500, 0.01224728, 0.00000000) P_x = 0.00000154I_y = (0.00000000, 0.00000128, -1.00000000) P_y = 0.00000390I_z = (-0.01224728, 0.99992500, 0.00000129) P_z = 0.00000471

Moments of inertia: (kilograms * square meters)

Taken at the center of mass and aligned with the output coordinate system.

L_{xx} = 0.00000154 L_{xy} = 0.00000004 L_{xz} = 0.00000000L_{yx} = 0.00000004 L_{yy} = 0.00000471 L_{yz} = 0.00000000L_{zx} = 0.00000000 L_{zy} = 0.00000000 L_{zz} = 0.00000390

Moments of inertia: (kilograms * square meters)

Taken at the output coordinate system.

I_{xx} = 0.00000177 I_{xy} = 0.00000221 I_{xz} = 0.00000000I_{yx} = 0.00000221 I_{yy} = 0.00002461 I_{yz} = 0.00000000I_{zx} = 0.00000000 I_{zy} = 0.00000000 I_{zz} = 0.00002403

Include Hidden Bodies/Components
 Show output coordinate system in corner of window
 Assigned Mass Properties

Mass properties of 7 (Assembly Configuration - Default)

Output coordinate System: -- default --

Density = 2493.18839434 kilograms per cubic meter

Mass = 0.03421781 kilograms

Volume = 0.00001372 cubic meters

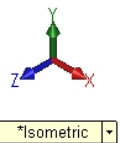
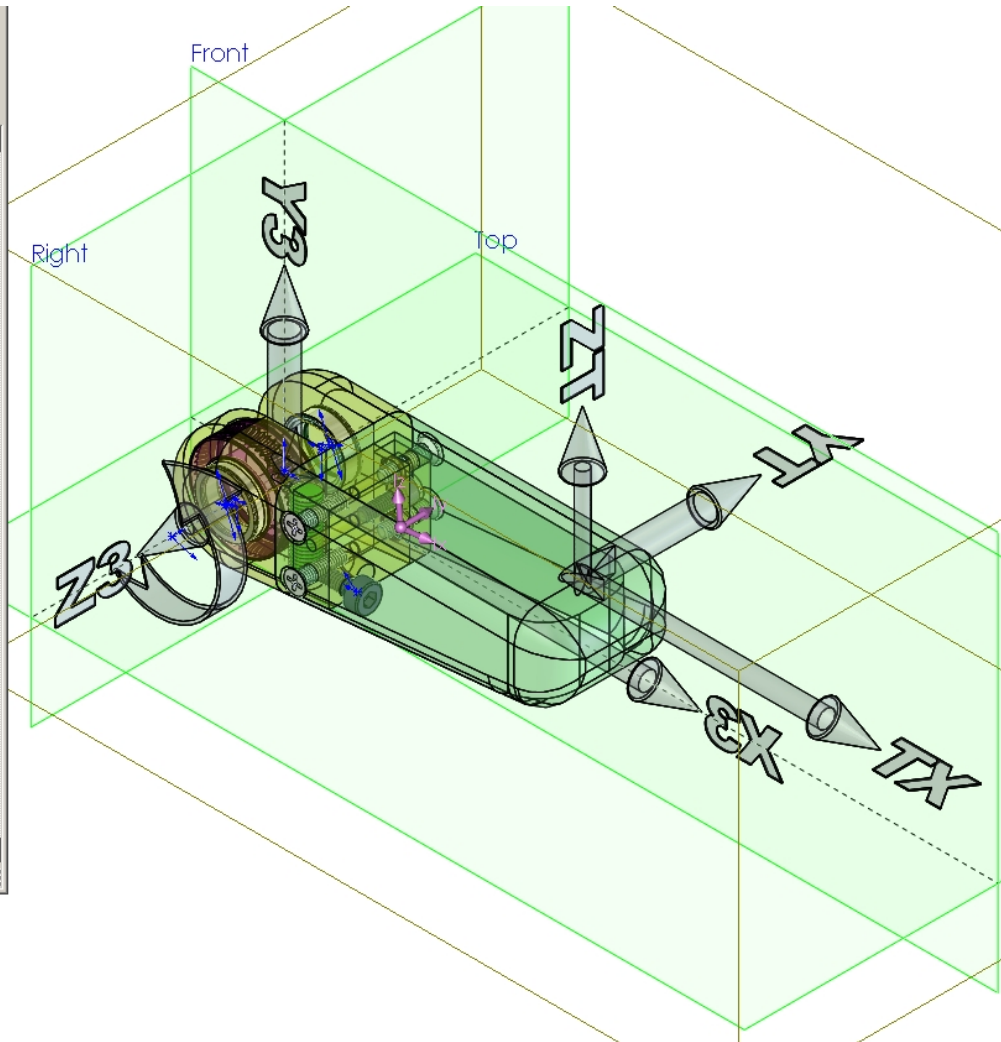
Surface area = 0.01467305 meters^2

Center of mass: (meters)
 X = 0.01970974
 Y = 0.00182016
 Z = 0.00020041

Principal axes of inertia and principal moments of inertia: (kilograms * square meters)
 Taken at the center of mass.
 Ix = (0.99621484, 0.08661050, -0.00739050) Px = 0.00000279
 Iy = (-0.00815345, 0.00845851, -0.99993099) Py = 0.00001214
 Iz = (-0.08654201, 0.99620634, 0.00913267) Pz = 0.00001336

Moments of inertia: (kilograms * square meters)
 Taken at the center of mass and aligned with the output coordinate system.
 Lxx = 0.00000287 Lxy = 0.00000091 Lxz = -0.00000007
 Lyx = 0.00000091 Lyy = 0.00001329 Lyz = -0.00000002
 Lzx = -0.00000007 Lzy = -0.00000002 Lzz = 0.00001214

Moments of inertia: (kilograms * square meters)
 Taken at the output coordinate system.
 Ixx = 0.00000299 Ixy = 0.00000214 Ixz = 0.00000007
 Iyx = 0.00000214 Iyy = 0.00002658 Iyz = 0.00000000
 Izx = 0.00000007 Izy = 0.00000000 Izz = 0.00002555



Mass properties of B3476 (Assembly Configuration - Default)

Density = 2493.18839434 kilograms per cubic meter

Mass = 0.03421781 kilograms

Volume = 0.00001372 cubic meters

Surface area = 0.01467305 meters²

Center of mass: (meters)

X = 0.01970974

Y = 0.00182016

Z = 0.00020041

Principal axes of inertia and principal moments of inertia: (kilograms * square meters)

Taken at the center of mass.

Ix = (0.99621484, 0.08661050, -0.00739050) Px = 0.00000279

Iy = (-0.00815345, 0.00845851, -0.99993099) Py = 0.00001214

Iz = (-0.08654201, 0.99620634, 0.00913267) Pz = 0.00001336

Moments of inertia: (kilograms * square meters)

Taken at the center of mass and aligned with the output coordinate system.

Lxx = 0.00000287 Lxy = 0.00000091 Lxz = -0.00000007

Lyx = 0.00000091 Lyy = 0.00001329 Lyz = -0.00000002

Lzx = -0.00000007 Lzy = -0.00000002 Lzz = 0.00001214

Moments of inertia: (kilograms * square meters)

Taken at the output coordinate system.

Ixx = 0.00000299 Ixy = 0.00000214 Ixz = 0.00000007

Iyx = 0.00000214 Iyy = 0.00002658 Iyz = 0.00000000

Izx = 0.00000007 Izy = 0.00000000 Izz = 0.00002555